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WATER POLLUTION PAPERS

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PAST, PRESENT AND FUTURE ENVIRONMENTAL
PROBLEMS WHICH CAN OCCUR IN CONSERVATION
AREAS DUE TO ENVIRONMENTAL DEGRADATION
BOTH WITHIN AND OUTSIDE THOSE AREAS

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PAST, PRESENT, AND FUTURE ENVIRONMENTAL PROBLEMS
WHICH CAN OCCUR IN CONSERVATION AREAS DUE TO
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THOSE AREAS.

PRESENTED BY:

MR. J. COATES,
ASSISTANT GENERAL MANAGER

HAMILTON REGION
CONSERVATION AUTHORITY

NOVEMBER 15, 1980.

For the information of those attending this morning's session, I think it is important that people know what a Conservation Authority is and how it operates.

The Hamilton Region Conservation Authority, one of 39 within the Province of Ontario, operates within the confines of the Conservation Authorities Act. This Act is administered by the Ministry of Natural Resources and it is through this Ministry that Authorities receive their provincial grants.

A Conservation Authority is a corporate body, the Board members being appointed by both the local municipalities as well as the Provincial Government.

The objects of a Conservation Authority are set out in Section 19 of the Conservation Authorities Act which states "The objects of an Authority are to establish and undertake, in the area over which it has jurisdiction, a program designed to further the conservation, restoration, development and management of natural resources other than gas, oil, coal and minerals."

As you can appreciate, the Authorities' activities in environmental matters fall within the terms conservation, restoration and management of natural resources.

I. First a Word about the Authority's General Water Quality Monitoring Program

The Authority conducts on an annual basis a fairly detailed water quality monitoring program within its area of jurisdiction. This program was originally conceived as a joint program with the Ontario Water Resources Commission in July of 1964. At that time, the Authority obtained stream samples at designated stations within the watershed and delivered them to the Ontario Water Resources Commission labs in Toronto for analysis.

In setting up the stations to be sampled, the Authority and the O.W.R.C. considered problem areas, as well as areas of special interest due to upcoming Authority project activities. The stations and reasons for their selection were as follows:

- #1. Redhill Creek at its confluence with the Windermere Basin - this station being selected to monitor the effluent from the Hamilton sewage treatment plant as well as other combined storm and sanitary overflows within the drainage basin.

- #2. Redhill Creek in King's Forest Park to monitor the Upper Ottawa Street dump.
- #3. The Burlington Canal to monitor the quality of water exchanged between the harbour and Lake Ontario.
- #4. The Desjardins Canal to monitor the effluent from the Dundas sewage treatment plant entering Cootes Paradise.
- #5. Spencer Creek at Cootes Drive to monitor the Spencer drainage basin above Cootes Paradise.
- #6. Spencer Creek at Crooks Hollow Road to monitor and provide background information to the Authority for the Christie reservoir project.
- #7. Spencer Creek at Valens Sideroad to monitor and provide background information for the Valens reservoir project.

This joint water sampling program was terminated in 1979. I believe some of the above stations are still being sampled by the Environment Ministry.

Parameters analyzed during this sampling program included total coliform, 5 day B.O.D., total and suspended solids, turbidity, total and soluble phosphorus, nitrogens including free ammonia, total kjeldahl, nitrite and nitrate, chlorides and dissolved oxygen.

The Hamilton Region Conservation Authority, which succeeded the Spencer Creek Conservation Authority in 1966, realized the value of this watercourse monitoring program. In 1966 the Hamilton Department of Municipal Laboratories was requested to undertake on the Authority's behalf a comprehensive sanitary survey of the creeks within its jurisdiction with a view toward the generation of data relevant to the development and management of water based conservation areas for recreation purposes. This program was initiated in 1967 with the Authority providing summer staff to obtain and deliver samples to the lab for analysis. An annual technical report is prepared for the Authority by the Director of the Municipal Lab, now the Regional Laboratory. Copies of this annual report are available at the Authority office as well as at the various libraries throughout the Region.

In 1974, all the data collected was placed on the City Hall computer for ease of retrieval and study, and in 1976, a report was prepared using data generated between 1967 and 1975 within the Spencer Creek drainage basin. This report involved a limited analysis of over 65,000 chemical and bacteriological tests performed on some 6,000 water samples collected over the period 1967 through 1975. The Spencer watershed was evaluated for 4 parameters - total coliform, fecal coliform, nitrates and phosphates.

Results of the study were very encouraging. Total coliform concentration increased significantly from an average of 550 organisms per 100 ml in 1967 to 1,600 per 100 ml in 1975, the greatest increase occurring between the Beverly Swamp and the Niagara Escarpment. Fecal coliform concentration, however, showed a significant decrease from 102 organisms per 100 ml to 55 per 100 ml, the most significant decrease noted at Crooks Hollow just below the Christie Dam. Nitrates and phosphates also showed significant decreases, nitrates from 0.95 parts per million in 1967 to 0.74 parts per million in 1975, and phosphates from 0.3 parts per million in 1967 to 0.02 parts per million in 1975.

The concentration of these 4 parameters for the months of July and August only, that period being the major water contact recreation period, was also considered. Again, total coliform concentration increased from a mean of 830 per 100 ml in 1967 to 2,400 per ml in 1975. The provincial criteria for total coliform organisms for water contact recreation is no greater than 1,000 per 100 ml. As in the analysis of all samples taken, similar decreases were observed in fecal coliform, nitrate and phosphate concentrations within the catchment area.

II. Stoney Creek Watercourse Study

In 1979, the Conservation Authority undertook a comprehensive water quality survey of the creeks entering Lake Ontario within the present Town of Stoney Creek. This survey was prompted by high total and fecal coliform concentrations along the waterfront at Confederation Park in 1978. Results of the study indicate that all but one of the 15 watercourses sampled were ranked as severely polluted, most of the time. Parameters sampled included total coliform, fecal coliform, ammonia and nitrate. The study showed that these streams contained both improperly treated domestic waste, as well as heavy loadings of treated waste. There is no doubt that at various times of the year, these streams could cause fairly severe local pollution along the Lake Ontario waterfront.

III. Past Environmental Problems

Since 1966, the Authority has encountered various environmental problems within its major multi-use conservation areas. I will outline some of the environmental problems encountered at both the Valens and Christie Conservation Areas and the measures taken by the Authority in order to control or eliminate these problems.

First, a bit of background information about these two areas.

The Valens Conservation Area is a 700 acre block of land containing a 185 acre surface manmade reservoir. This reservoir serves a multi-use function including that of flood storage, stream flow augmentation, and water based recreation including swimming, boating, and fishing. The reservoir was stocked with large mouth bass and northern pike in 1966 and maintains a self sustaining fishery.

The Christie Conservation Area is an 838 acre property containing a 149 acre surface manmade reservoir. This reservoir also serves a multi-use function, including flood storage, pollution abatement, flow augmentation, and water based recreation including both swimming and boating as well as limited fishing for coarse species. The reservoir is not stocked for use as a sport fishery since it is drawn down to creek level each fall and is held at this stage until the following spring freshet has passed.

Land Acquisition Planning for Environmental Control of Reservoir Water Quality

1. The Conservation Authority, in its land acquisition program for these two projects, recognized the value in being able to control land use activities and possible contamination of the reservoir by purchasing substantial land area surrounding the water body. In the case of Valens, the total land acquired was approximately $3\frac{1}{2}$ times the reservoir surface area and in the case of Christie, the land purchased was approximately $5\frac{1}{2}$ times the reservoir surface area.

The following are some problems encountered with point sources of contamination.

2. During the late 1960s and early 70s the Valens reservoir experienced high total and fecal coliform and nutrient levels entering by way of the inflowing watercourses. This surge of contamination was traced to an upstream chick

production facility known as Shaver Farms. Shaver Farms produces special hybrid chicks which are sold throughout the world for subsequent egg production. Waste fecal material from the Shaver operation was being spread on fields above the reservoir. This waste material was not properly ploughed into the soil and consequently during periods of high runoff, contributed large doses of fecal, coliform and nitrogen contamination to the reservoir. Once the source was confirmed, the Authority requested a joint meeting with the company, the local Environment Ministry and a representative of the local Agricultural Ministry. The Authority was able to place its evidence before company officials and left the meeting with a promise by the company that a proper, well co-ordinated waste management program would be implemented at once. In this particular case, one meeting was sufficient to produce a total resolution of the problem. The Authority continues to monitor inputs to the reservoir in case of new problems or recurrence of past ones.

3. In 1966, the Conservation Authority began acquisition and construction for the Christie dam and reservoir just above Crooks Hollow Road in Flamborough Township. Development plans were prepared to guide development of the surrounding land area as a major regional recreational facility. The Spencer Creek, as it flows through the Christie Area, becomes the receiving stream for effluent from two local industries. One of these is Dundas Producers located on #8 Highway south of the reservoir. Dundas Producers, a division of Robin Hood Multi-Foods, processes chicken carcasses for public consumption; the other company is the Ontario Rendering Company, or Orenco, which recycles waste animal products by rendering them into fats. The waste effluents of both these companies were not of sufficient quality for release to a water body used for public recreational use. During the period that the conservation area was under development, both companies were requested to improve the quality of their effluents by installing additional treatment facilities. This was done and since the conservation area was opened to the public in 1974, these companies have continued to upgrade both their air and water treatment capabilities in order to guarantee a good quality effluent to the receiving water body.

4. One of the major problems encountered by the Authority is Eutrophication within its reservoirs. Eutrophication is the natural aging process of shallow nutrient rich, warm bodies of water. This process results in the conversion of a lake to a marsh.

This process is most pronounced in the Valens reservoir. Analysis of inflow waters over the years indicates that normal runoff from the woodland above the reservoir is extremely rich in nutrients.

These nutrients have caused excessive aquatic weed and algal production within the reservoir to the point where the reservoir becomes quite choked with aquatic weeds by later summer. The subsequent die-off and decay of these aquatic weeds and algae result in low oxygen concentrations, particularly in the lower depths of the reservoir. Low dissolved oxygen has been responsible for several severe winter fish kills at Valens, particularly during those winters when ice and snow cover remain on the reservoir for an extended period of time. Anaerobic conditions on the bottom of the reservoir also result in a thick sludge inhabited by the red sewage worm.

In 1972, on the recommendation of the Ministry of the Environment, the Authority installed a destratifier within the Valens reservoir. This destratifier consists of a compressor which pumps air through plastic lines to diffusers located in the bottom of the reservoir. The movement of air bubbles from the diffuser on the bottom up to the surface creates a circulation current within the reservoir. This mixes the lake water, bringing oxygen rich surface water in contact with the sludge on the reservoir floor. The sludge is thereby oxidized, slowing down the aging process and eliminating the associated odours and sewage worms. This oxidization process is also thought to release iron compounds from the sludge which provide a measure of control on algae production.

Results of this destratification process were so good that the compressor was removed in 1977 without a recurrence of the problems. We have also noted that the blooms of algae that occurred on the major lower section of the reservoir have been eliminated, however the problem with aquatic weeds remains and the Authority is presently investigating various methods of control.

In the Christie reservoir, this aging process is not as pronounced. The reservoir waters at Christie contain higher levels of suspended solids which curtail light penetration of the reservoir. Both aquatic vegetation and algae require high light levels to grow.

Swimming Area Water Quality

5. Pollution of swimming areas has, in the past, been a serious problem at both the Valens and Christie reservoirs. This problem results when the total coliform concentration reaches 1,000 organisms per 100 ml and when fecal coliform levels reach 100 organisms per 100 ml. Swimming facilities at Christie and Valens are sampled frequently by local Health Unit personnel and swimming facilities are posted when high coliform counts occur. Closure of the beaches results in bad publicity for the Authority as well as a resultant loss of conservation area revenue.

High coliform levels within our swimming areas have been traced to a number of sources, including (a) farm drainage from barnyards, feedlot, and liquid manure disposal, (b) Canada geese, ducks and gulls in the beach area leaving their excrement on the waterline, (c) swimmers during periods of heavy use, (d) malfunctioning septic systems both within and outside the conservation area, (e) vandalism to swimming barriers allowing reservoir water to enter the swimming area without chlorination.

Eliminating all of the above causes of pollution is not always possible, particularly where agricultural pollution is concerned. The Authority installed in 1973 and 1974 an artificial barrier around the swimming areas at both Valens and Christie in order to control water quality.

This swimming barrier was first used by the City of Cleveland, Ohio in its "pools in the lake" project. The swimming barrier, fabricated of a vinyl coated polyester material with an attached flotation collar, encloses the swimming area, completely segregating the water within the area from the rest of the lake. Chlorination then guarantees the quality of the water within the swimming area for public use. The reservoir area outside the swimming barrier is protected from chlorination, thereby ensuring the continuance of a diverse biological community which would otherwise be destroyed by the chlorine.

Gas chlorinated swimming areas have been operated at both Valens and Christie since the summer of 1975 with very little problem, thus resulting in high public acceptance of these areas for summer recreational use.

6. Swimmer's Itch

In 1972, the Conservation Authority experienced a severe outbreak of "swimmer's itch" (Schistosome dermatitis) at the Valens Conservation Area. Swimmer's itch is caused by the penetration of the human skin by the cercaria stage of the Trematode flatworm. This blood fluke is parasitic in birds and mammals, particularly waterfowl. The cercariae are free swimming, colourless, and approximately 0.7 mm in length. The adult blood fluke is parasitic in the veins of birds and mammals; in the case of Valens, ducks, geese and possibly muskrats. The fertilized female lays her eggs in the bird or mammal host which then passes these eggs into the lake water with their feces. The egg contains an embryo which, upon hatching, develops into a stage called miricidium. The miricidium in turn infects a suitable species of snail and the cercariae stage is produced within the snail host and emerges from the snail to swim about in search of a proper waterfowl or mammal host to penetrate, in which it can develop to maturity, thus completing the life cycle.

This cycle is interrupted accidentally when these cercaria penetrate the skin of bathers. Following penetration of the human skin, the cercaria are destroyed by the body defenses, but cause acute inflammatory reactions known as swimmer's itch (or schistosome dermatitis).

Studies at Valens have determined that both waterfowl and the particular species of snail required to complete the life cycle of the parasite were present in great abundance. Several methods of control were undertaken, ranging through:

1. Removal of geese from the area
2. Control of aquatic weeds by chemical treatment, mechanical cutting and removal, and controlled winter reservoir drawdowns.
3. Physical removal of snails from the beach area.
4. Segregation of the beach area with the swimming barrier and chlorination to kill the cercariae.

The segregation of the beach area with the swimming barrier and subsequent chlorination has proven 100% effective against swimmer's itch, provided, of course, the swimmers remain inside the regulated swimming area.

Geese are removed from the Valens reservoir on an annual basis when they become flightless, providing a partial solution to both the swimmer's itch and fecal coliform pollution problems. In fact, the incidence of infected snails dropped from 25% to 1.59% with the removal of geese from the reservoir.

Chemical weed control can be harmful to fish populations within the reservoir if applied throughout the lake. Partial treatment within the swimming area, however, has been successful in controlling the growth of aquatic weeds. Mechanical cutting must be accompanied by a removal of cut weeds from the lake to prevent oxygen depletion and sludge buildup. Mechanical cutters are expensive to operate and they are only effective in shallow water areas.

Winter reservoir drawdown has proven effective during severe winters; freezing of the roots of aquatic vegetation retards their growth the following season. The Authority, however, is limited in the amount of drawdown possible at Valens because of the fishery in the reservoir. Excess drawdowns result in winter oxygen depletion and severe fish kills.

Manual removal of snails from the beach area by lifeguards has proven effective.

During the past 3 years, the Valens reservoir has experienced an almost complete die off of the alternate host snail. Why this has occurred, we don't know. We think that the snail population likely reached such a high density that the snails became stressed or diseased. One would have a hard time today finding a single snail of the specie "limnaea stagnalis" at Valens.

7. Sewage Disposal Within Conservation Areas can be a Problem

Major Authority conservation areas such as Valens and Christie are developed in association with reservoirs and waterfront activities. Extensive public use of these areas for swimming and picnicking results in the generation of large amounts of sewage within the area which must be disposed of without deterioration of the resource. In virtually all cases, the soils along the shores of streams and reservoirs are not compatible with sewage disposal and local municipal sewers are not available.

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The Authority has therefore found it necessary to design and install extensive septic sewage disposal facilities and, in some cases, large watertight concrete holding tanks. Sewage generated at both the Valens and Christie facilities is pumped up to 1/4 mile back from the reservoir to be disposed of in large tile beds containing up to two miles of tile. In addition, large 30,000 gallon holding tanks are installed in the campgrounds at Valens. These tanks are pumped out under contract by a local contractor.

Following an initial problem with in-area generated sewage disposal in 1968 at Valens, the installation of these large tile bed facilities have proven effective in sewage disposal.

IV. The Present and the Future

And now, something about present and future environmental problems.

1. I have already referred to the results of a study conducted in 1979 on the streams and outfalls entering Lake Ontario within the Town of Stoney Creek. These severely polluted watercourses must be cleaned up as soon as possible.
2. With the increased cost of fuel, residents of the Hamilton-Wentworth area will make more and more use of the Lake Ontario waterfront for recreational pursuits. This area has the potential to satisfy many of the needs of the local population in the years to come. This resource must be preserved and improved.

Since 1975, the Conservation Authority has become increasingly active along the Lake Ontario waterfront. Projects such as the acquisition of the Beach Strip for open space purposes as well as the development of the 50 Point Conservation Area for boating, fishing, picnicking, swimming, and camping is well underway. The Conservation Authority has more recently become involved in the management of Confederation Park, a major regional waterfront development. The Authority has also over the past year shared in the cost of a comprehensive land use study of the Stoney Creek waterfront with the Town of Stoney Creek. This land use study, when completed, will provide both the Town and the Authority with an open space plan for the Lake Ontario waterfront.

If any of you have had the opportunity to see what is taking place today on the Toronto waterfront, you will appreciate the potential of what we have here in Hamilton-Wentworth. Our future as a region for leisure recreation lies along the Lake Ontario waterfront. We must work diligently over the next decade to resolve those current and future environmental problems which will negatively affect this resource.

3. There are many issues with which we must deal. A solution to the problems of mercury, PCB, dioxin, mirex and other chemical pollutants in Lake Ontario must be found. These pollutants are seriously affecting the quality of the extensive fisheries revitalization program presently underway in the lake. The Great Lakes Guide to Eating Ontario Sport Fish recommends only occasional meals of those edible fish caught in the western basin of Lake Ontario.
4. Most of the watercourses, draining into Lake Ontario have little flow during certain times of the year. Pollutants accumulate in standing pools and the degradation from the first flush after a rainstorm can cause serious environmental problems. It will be necessary at some point in the future for the collection of this "first flush" in large holding tanks and for this runoff to be redirected to the regional sewage treatment plant for processing.
5. Erosion along various sections of the lakefront is serious, especially when high waves occur during periods of high lake levels. A public open space buffer has been recommended along the shoreline, with the construction of extensive erosion control works to preserve the land resource adjacent to the lakeshore.
6. The preservation and integration of various land uses along the waterfront, including housing, agriculture and open space is required. Soils in the Stoney Creek waterfront area consist of highly impervious clays unsuitable for septic sewage disposal facilities. It will be necessary to provide the area with sanitary sewers and at the same time to resist attempts to justify the installation of these sewers, by developing the area completely for housing, commercial and industrial uses. Remember, recreational facilities require sewers as well.

7. Floodplain delineation, management and acquisition is extremely important within our Region. The potential for large financial loss and loss of life due to flooding increases dramatically with increased densities. In addition, natural stream valleys and watercourses provide benefits in filtering pollutants from streams as well as providing linear open space and green buffers between communities.
8. The Mount Albion Conservation Area faces many present and future environmental problems. This area located within the City of Hamilton just south of Albion Falls is traversed by the Redhill Creek. This creek is severely polluted with septic waste and leachate from the Upper Ottawa landfill site. Proposed new highways will bisect the area reducing its potential for future recreational use. The conservation area is surrounded by industrial land use. We must ensure that sufficient controls are in place to see that the types of industrial uses are compatible with the area. The area is also on the receiving end of a number of existing and proposed storm sewer outfalls. These will have a major effect on the stream and its environs with respect to both water quality and erosion.

V. Conclusion

No doubt, there will be many other environmental issues and problems to solve. Perhaps this paper which deals with a few of our past, present and future problems will provide some thought and awareness to the participants in this session.

Thank you.

Sources of pollution, their impact

and biological processes in

Hamilton's receiving waters

by

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Preamble

The waters in, and around the Regional Municipality of Hamilton-Wentworth are unique and varied. They represent a singular resource for the Region in that they are a source of drinking water, a transportation corridor, a recreational resource and a means of disposing of industrial and municipal wastes. There must inevitably be conflicts between these multiple uses and with the interests of conservation. Water bodies are biological systems as well as large bathtubs for the use of ships and for the receipt of wastes. We intend to demonstrate that only through a good knowledge of biological, physical and chemical processes can we arrive at sensible management strategies. Too often the biological component is ignored.

Background Studies

The waters in and around Hamilton range in size from the shallow open area of the Dundas Marsh through Hamilton Harbour to the coastal zone of Lake Ontario - one of the larger lakes in the world. In depth they range from 3 feet to 800 feet. All three bodies of water are connected by channels so they are essentially parts of one system. They cannot be studied independently.

Systematic sampling of the Dundas Marsh was begun in 1973 (1) and has been continued by a number of agencies since that date (2). The Marsh is heavily polluted and highly eutrophic (Table 1). Hamilton Harbour has the distinction of being one of the most heavily polluted water bodies in the Great Lakes System (Table 1). The Harbour receives massive loadings of a variety of pollutants from a variety of sources and presents, in consequence, a considerable water quality management problem. This paper is an attempt to summarize what has been learned from a number of years of research in the Harbour. The studies

Table 1.

	TP ¹	loading ²	Chl _a ¹	Z _{eu} ³
Coote's Paradise	155	22.4	92.8	1.0
Hamilton Harbour	110	10.5	28.5	3.5
Saginaw Bay (inner)	60	---	29.0	3.6
West	35	6.0	11.1	
Lake Erie Central	27	0.9	6.5	≈10
East	20	0.75	5.2	20
Lake Ontario (central)	20	0.75	5.0	20
Lake Huron	5	0.10	2.0	≈40
Lake Superior	5	0.05	1.0	≈40

Total Phosphorus (TP), Phosphorus loadings, average annual chlorophyll concentration (Chl_a) and euphotic zone depth (Z_{eu}) for representative water bodies in the Great Lakes.

¹ μg.L⁻¹

² gTP.m⁻².y⁻¹

³ metres

span the period from 1975 to the present and were funded by the National Sciences and Engineering Research Council, Environment Canada, and by the Ontario Ministry of the Environment (OME). As much of the data to be presented here appears elsewhere in the scientific literature, this paper will present them in a more compressed and accessible form.

OME studies (3, 4, 5) in the early 1970's indicated that the waters of the Harbour were highly eutrophic and that oxygen depletion in bottom waters in summer occurred rapidly and was extensive. In 1975 OME began an experimental programme to control this oxygen depletion problem by installing a 3000 ft air bubbler sytem to mix the Harbour water vertically. It was recognized at an early stage (6) that this measure would only ameliorate the symptoms of the basic problem. Only a reduction in the pollutant loadings to the system would produce any long term improvement in water quality.

Lake Ontario, the source of the Region's drinking water, receives wastes from upstream (Lake Erie and the Upper Lakes) as well as from towns and cities in the Lake Ontario basin (7). Lake Ontario receives a total phosphorus loading of approximately 6,500 metric tons per year of which about one half comes from upstream connecting channels (Niagara River) and one quarter comes from municipal point sources. The complexity of the biological, physical and chemical processes which control water quality may be illustrated by the fact that whereas total and soluble phosphorus levels in Lake Ontario have fallen sharply since 1973 (8) the inputs of total P to the Lake have, if anything, increased since 1973 (9). This means that processes within the lake are not at equilibrium with the changes in pollutant loadings over very long time periods (10).

The Biological Response to Nutrient Loadings

The loadings of nutrients to the Dundas Marsh, and to Hamilton Harbour are extremely high (Table 1). In both cases the sources of the nutrients are municipal sewage treatment plants (STP's). The Dundas STP is the largest single source of nutrients entering the Marsh with historical phosphorus loadings approaching 46 Kg.d^{-1} . The present plant is limited to 9 Kg.d^{-1} . Spencer Creek brings in 65 Kg.d^{-1} in the brief spring runoff but only 0.7 Kg.d^{-1} in the low summer flow.

The loadings to the Harbour have been published recently (11) and those conclusions may be summarized as follows. 57% of the total P loading comes directly from Municipal STP's (348 Kg.d^{-1}) and a further 14% (88 Kg.d^{-1}) comes from the Dundas Marsh. Thus 71% of the Harbour loading of total P originates from STP effluents. Natural streams produce 11% of the total P loadings and industry 12%. Total nitrogen loadings to the Harbour are very large. 81% of the total N loadings originate directly from STP effluents and total some $15,000 \text{ Kg.d}^{-1}$.

There are large inputs of metals, organics and other compounds (see next section) into the Harbour. Fortunately growth of planktonic algae in the Harbour shows significant resistance to the poisonous effects of zinc and copper (12) suggesting that they have adapted to these partially toxic conditions. In the past five years we have not observed any toxic effects on the algae in the Harbour from inputs of metals, cyanides, phenols or other organic chemicals. So far we can explain the phenomena which we have observed in terms of the interactions between physical mixing processes, the loadings of nutrients from the STP's and the biological response of the organisms to these factors.

A number of international studies have demonstrated that phosphorus is the key element limiting the abundance of algae in fresh waters (13). Phosphorus loadings cause an increase in the abundance of the planktonic algae in surface waters. By themselves the total P loadings to the Harbour ($10 \text{ grs m}^{-2} \text{ y}^{-1}$, Table 1) are sufficient to cause hyper-eutrophic conditions. The harbour does not, however, produce as many algae as empirical eutrophication-loading models predict (11). The reason for this lies in the continual exchange of water between the three water bodies. Calculation of the hydraulic residence times for the Marsh and for the Harbour (11) indicate that these exchanges of water dominate the flow and ensure that total P concentrations in the Marsh and the Harbour are continually "diluted" by water from Lake Ontario (Table 2). When the Lake exchange was included the Harbour and the Dundas Marsh conformed precisely to the predictions based on OECD data (13).

Temperature and Oxygen Profiles

Thus the exchange of water with Lake Ontario through the Burlington ship canal is a vital component in the overall ecology of the system. The effects of this exchange were also evident in the temperature and oxygen profiles which are observed in the Harbour (see next section). Computer models of the temperature structure of the Harbour always predicted much warmer bottom water than was observed in summer. The bottom waters of the Harbour also showed the presence of irregular pulses of oxygen during the summer months. These two phenomena were produced by incursions of cold, oxygen-rich hypolimnetic waters from the Lake (cf. Fig. 4). Thus there were some complex two-way exchanges through the Burlington ship canal with warmer surface water moving out into the Lake and colder bottom water sliding in underneath. These irregular exchange events driven by the wind and caused major modifications in the temperature structure of the water.

Table 2. (1976 data)

	Area Km ²	mean depth m	T _w no E	E ¹	T _w + E water residence time
Dundas Marsh	1.61	0.7 m	52.4 days	18.8 Q	2.78 days
Hamilton Harbour	21.5	13 m	1 year	6.8 Q	46 days
Lake Ontario	20,000	80 m	8 years	---	---

¹ as multiple of annual flow

T_w - water resident time

E - lake exchange as a multiple of Q, the annual input of water from
all other sources

The Harbour has a long history of oxygen depletion problems (3-6).

The oxygen demand from the decomposition of organic material exceeds the supply so that in summer the colder bottom water rapidly becomes anoxic. Previously published data (14) has demonstrated that the extent of the oxygen depletion in bottom waters and the speed of the oxygen decline in spring were dependant on the climate in the spring of each year. The 'leaky' thermocline in the Harbour allowed vertical transfer of oxygen to occur (11, 14, 22) so that the temperature structure of the water in each year determined the rate of net oxygen depletion in May and June, and caused the surface waters to be relatively oxygen depleted. The oxygen concentration in surface waters is dragged down by the high demand at the bottom. Exchange with Lake Ontario has a very great effect on this whole process as the Lake exchange weakens the temperature gradient in the middle of the water column (increasing the 'leakiness') and oxygenates the bottom waters. Oxygen maxima often occur at 16-17 m down (11, 14).

Hamilton Harbour is unusual as the majority of the oxygen demand comes from the decomposition of organic material in the water column (11, 14). Bacterial action oxidises the organic material which enters the Harbour in the STP effluent. As well as providing a source of biological oxygen demand these organic materials have a vital effect on light penetration in the Harbour (11, 14, 15, 16). The Harbour water is very black.

When the OME began the mixing experiment in 1975 the magnitude of these exchanges was not appreciated. The exchange with the lake was large enough (Table 2) to mask any effects from the artificial mixing experiments and the project has consequently been terminated. In essence the lake exchange was already acting as an enormous mixing mechanism. Lake exchange reduced the amount of total P in the water, reduced the abundance of the algae, prevented

the growth of nuisance blooms and caused a certain amount of re-oxygenation in bottom waters. The physics of the three basin system controls the water quality that we observe and were it not for the exchange phenomena the waters of the Dundas Marsh and Hamilton Harbour would surely exhibit much larger algal blooms, the growth of nuisance algae and, possibly, the development of taste and odour problems in the water. Isolation of the Marsh by a weir (which has sometimes been suggested) is therefore highly undesirable.

The natural heating and cooling cycles of the Harbour, together with the wind-driven exchange with Lake Ontario produce some highly complex temperature distributions in the Harbour water. Recent research has demonstrated that these varying conditions of solar heating and wind mixing drive all the biological processes in the Harbour. The physiology of the algae (15, 16) and the entire community structure (17, 18, 19) responded to the physical variability in this nutrient saturated system. Our research in the Harbour has led us to formulate some improved ideas concerning the operation of biological processes in lakes and the oceans (19, 20).

Case Study - Computer Models and Management

Consider the following example of the need for basic research plus the basic engineering tools of mathematical models which, when properly constructed provide an ability for management decision making where hypolimnetic dissolved oxygen is a main concern.

Based upon monthly estimates of hydraulic inputs from the various sources flowing into the Harbour (Wastewater Treatment Plants, storm water overflows, surface streams and the Dundas Marsh), an estimate of the monthly variation in

TABLE 3

MONTHLY VARIATION IN DETENTION TIME ESTIMATES BASED EITHER ON
LAND RUNOFF OR LAND RUNOFF PLUS WWTP DISCHARGES

MONTH	DETENTION TIME* (yr)					
	1975			1976		
	FLOW FROM LAND RUNOFF**	FLOW FROM ALL SOURCES***	FLOW FROM LAND RUNOFF	FLOW FROM ALL SOURCES	FLOW FROM LAND RUNOFF	FLOW FROM ALL SOURCES
January	2.9	1.4	2.3	1.2	7.0	1.7
February	1.2	0.83	0.44	0.37	4.3	1.2
March	0.61	0.49	0.33	0.28	0.38	0.32
April	1.0	0.74	0.78	0.58	0.83	0.59
May	2.9	1.4	0.95	0.68	3.6	1.4
June	6.8	2.0	3.6	1.5	6.7	1.7
July	11	2.3	3.9	1.6	5.2	1.9
August	5.9	1.8	7.5	2.0	6.1	1.7
September	2.7	1.3	1.6	0.97	1.4	0.86
October	2.4	1.3	2.5	1.2	1.0	0.70
November	1.6	1.0	3.2	1.5	1.2	0.81
December	1.6	0.94	5.0	1.7	0.69	0.52

* Detention time estimate is the time required to fully displace harbour volume of water at the respective monthly flow rate.

** Hydraulic detention time based upon flow from all stream and storm water discharges to the harbour.

*** Hydraulic detention time based upon flow from all streams, storm water discharges and the three waste water treatment plants (Hamilton, Burlington, Skyway and Dundas).

Annual variations of the exchange coefficient, α^*

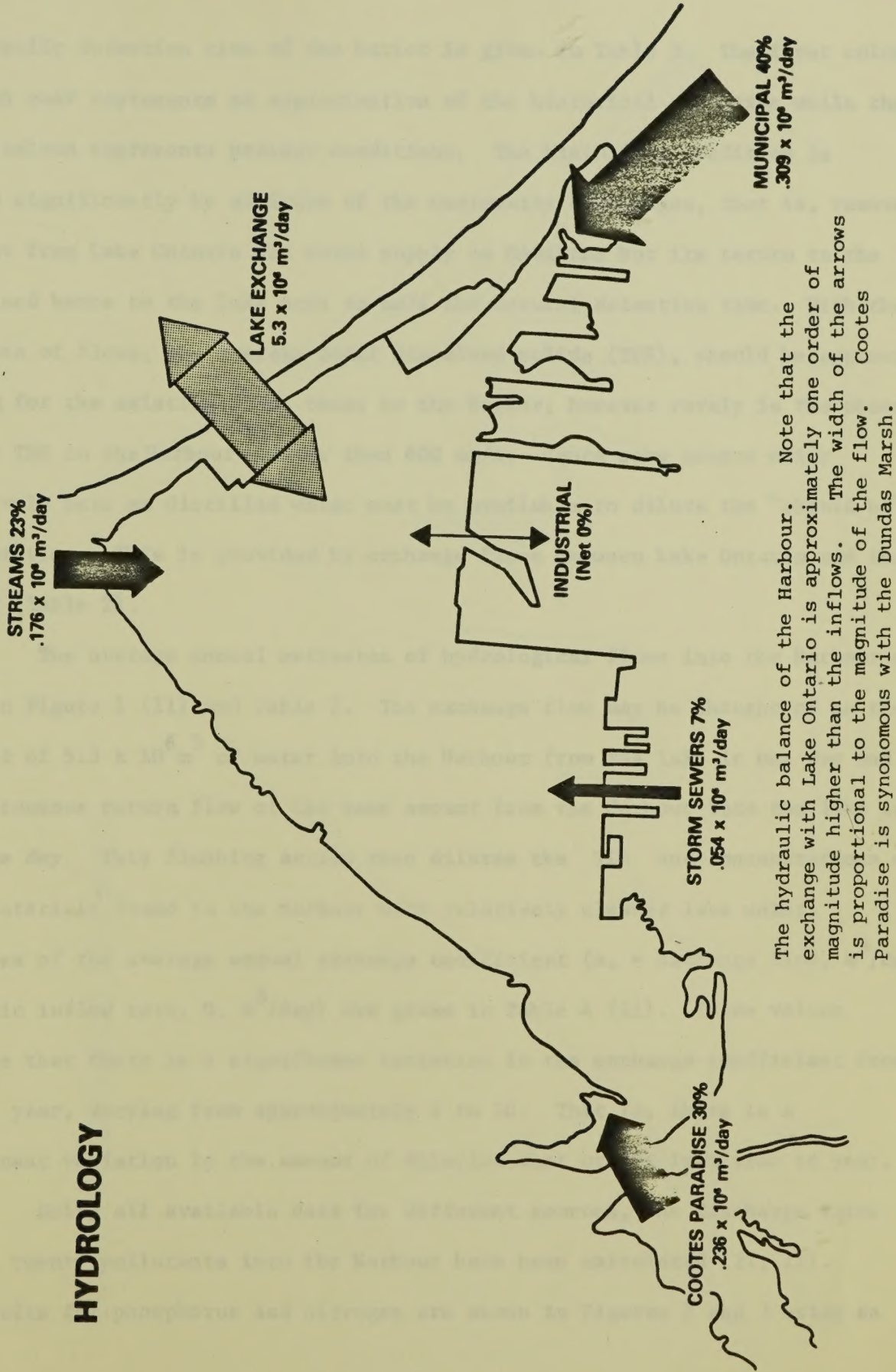
YEAR	α
1967	10.2
1968	2.5
1969	2.6
1970	1.2
1971	1.5
1972	4.9
1974	6.2
1975	4.9

*

α is defined as the ratio of the one directional flow rate between the Harbour and the Lake divided by the average annual inflows from surface streams and wastewater discharges.

Table 4

HYDROLOGY



The hydraulic balance of the Harbour. Note that the exchange with Lake Ontario is approximately one order of magnitude higher than the inflows. The width of the arrows is proportional to the magnitude of the flow. Cootes Paradise is synonymous with the Dundas Marsh.

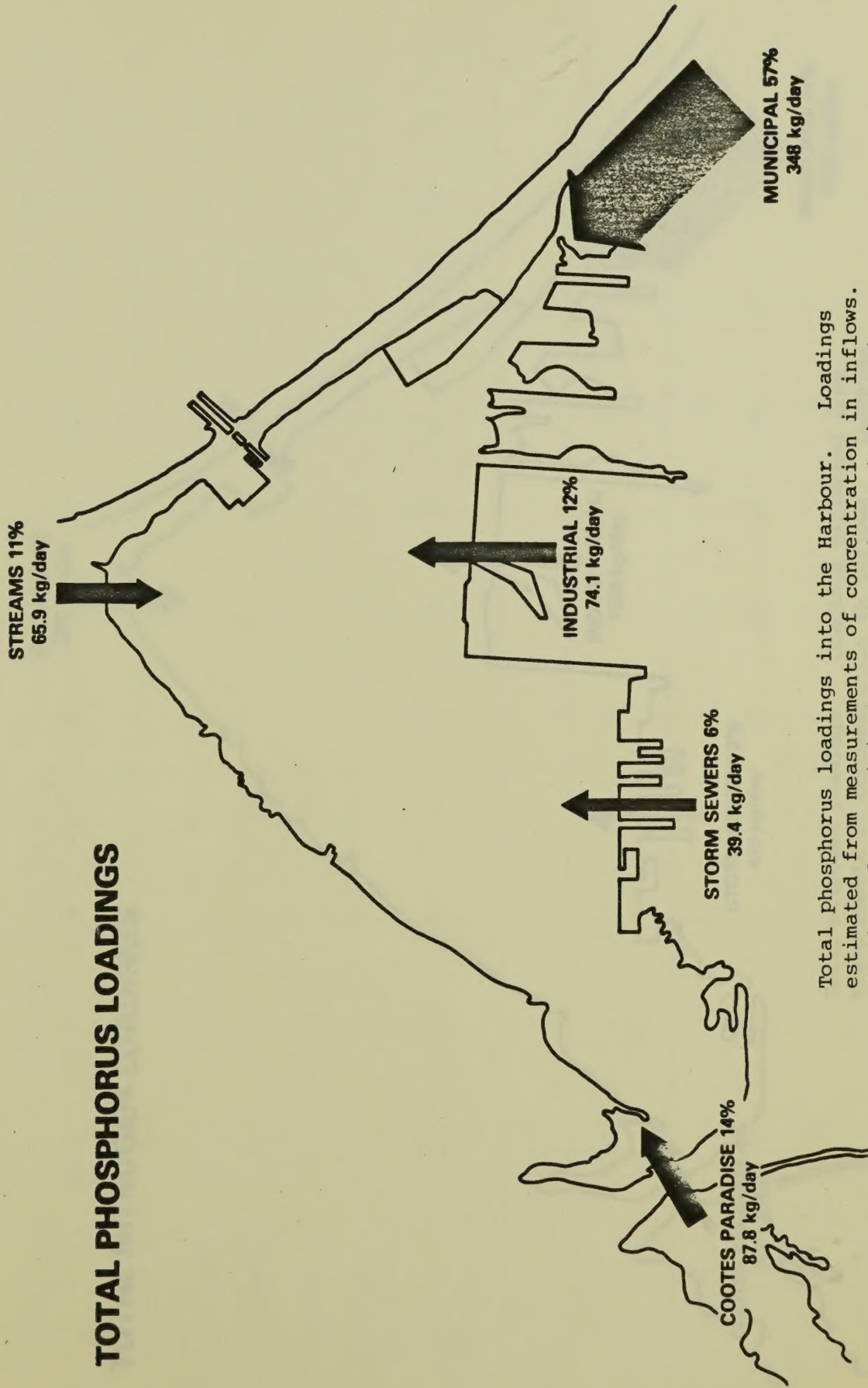
Figure 1

in hydraulic detention time of the harbor is given in Table 3. The first column for each year represents an approximation of the historical condition while the second column represents present conditions. The historical condition is changed significantly by addition of the wastewater discharges, that is, removal of water from Lake Ontario for water supply to Hamilton but its return to the Harbor and hence to the lake acts to half the natural detention time. With these estimates of flows, the average total dissolved solids (TDS), should be approximately 700 mg/l for the existing input rates to the Harbor; however rarely is the observed average TDS in the Harbour greater than 400 mg/l. Hence some source which effectively acts as distilled water must be available to dilute the "should be" concentration. This is provided by exchange flows between Lake Ontario and the Harbour (Table 2).

The average annual estimates of hydrological flows into the Harbour are given in Figure 1 (11) and Table 2. The exchange flow may be thought of as the movement of $5.3 \times 10^6 \text{ m}^3$ of water into the Harbour from the lake in one day and a simultaneous return flow of the same amount from the Harbour into the lake in the same day. This flushing action then dilutes the TDS and concentrations of other materials found in the Harbour with relatively cleaner lake water. Estimates of the average annual exchange coefficient (α , = Exchange flow, m^3/day , / Hydraulic inflow rate, Q , m^3/day) are given in Table 4 (21). These values indicate that there is a significant variation in the exchange coefficient from year to year, varying from approximately 1 to 10. That is, there is a significant variation in the amount of dilution that occurs from year to year.

Using all available data for different sources, the discharge rates of some twenty pollutants into the Harbour have been calculated (21, 11).

The results for phosphorus and nitrogen are shown in Figures 2 and 3 using an



Total phosphorus loadings into the Harbour. Loadings estimated from measurements of concentration in inflows. Loadings from municipal treatment plants dominate the overall load.

Figure 2

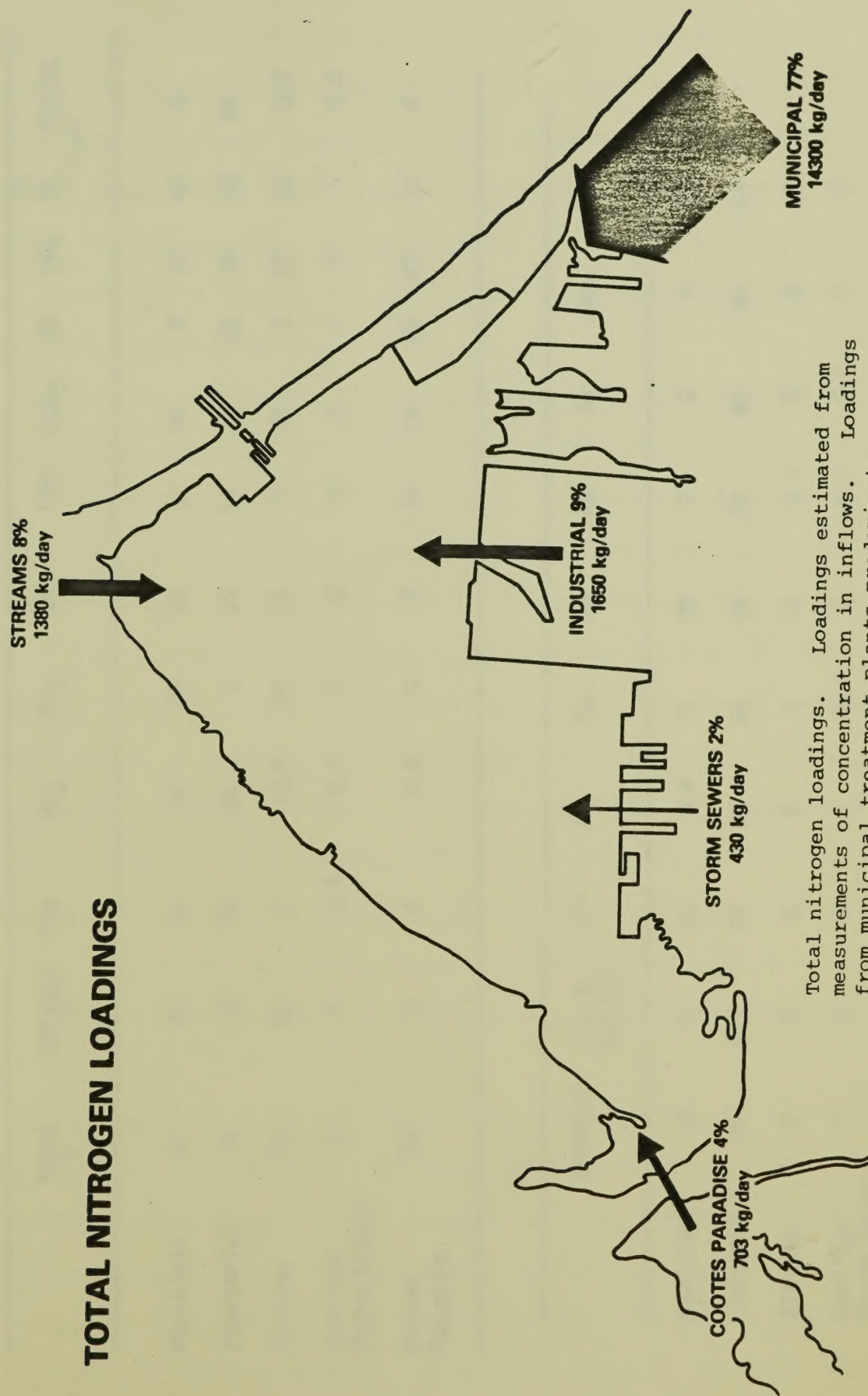


Figure 3

PERCENTAGE OF INPUTS TO HARBOUR FROM MAJOR SOURCES

	TOTAL P	SOLUBLE P	TKN	NH ₃	NO ₃	TOC	COD	BOD ₅	SS	TDS	CL CL _{total}	PHENOL
Municipal	52	79	54	74	59	40	22	35	9	32	41	0
Industrial	14	0	40	24	4	35	54	38	55	18	19	99
Streams	14	12	1	0.5	26	14	7	10	9	22	22	0.5
Hamilton Storm Sewers	2	4	0.6	0.5	2	2	2	3	1	2	1	0.5
Cootes Paradise	18	5	4	0.8	9	9	15	14	26	26	17	0

	CYANIDE	OIL & GREASE	H ⁺ *	Fe	Cu	Pb	Zn	As	Mn	Cr
Municipal	0	0	58	0.8	11	20	7	0	4	27
Industrial	100	100	28	96	83	44	90	80	80	64
Streams	0	0	8	0	1	13	0.4	0	3	3
Hamilton Storm Sewers	0	0	0	0	0.3	3	0.7	0.5	1	1
Cootes Paradise	0	0	6	3	5	20	2	20	12	5

* Budget for H⁺, not total H

arrow diagram (11). These diagrams show for conditions representative of the late 1980's, that municipal treatment plants (Burlington, Hamilton) are the dominant sources of nutrient inputs. The data is shown for the remainder of the pollutants in Table 5 (21). Note that the estimates shown in Figure 2 and 3 made in 1978 (11) are somewhat but not significantly different from those given in Table 5 (21) as more complete information was made for the more recent calculations given in Table 5 and made in 1980.

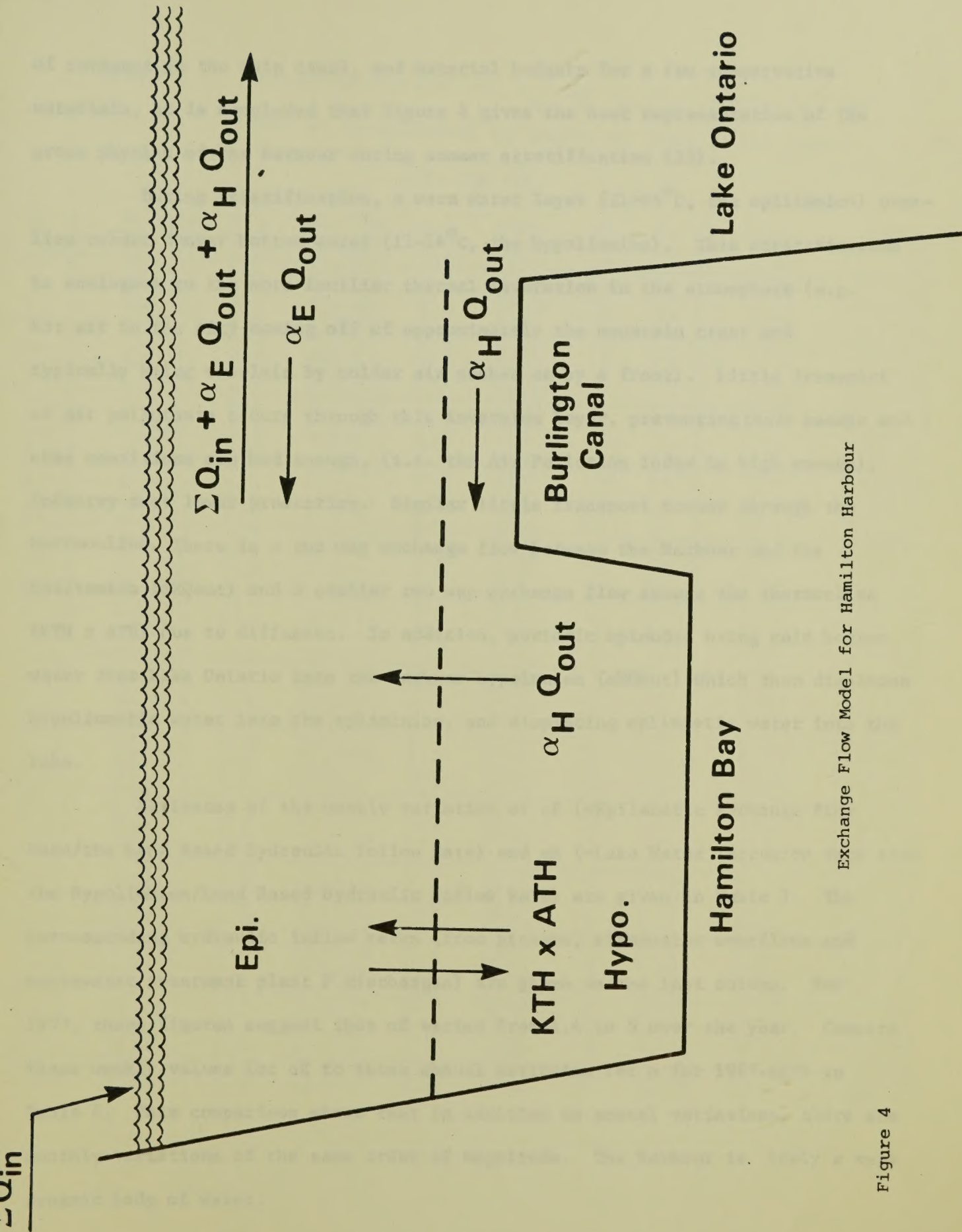
Another way of displaying this information is given in Table 6. The average inflow concentration is the concentration that would be found in all discharges (streams, stormwater overflows, treated wastewater discharges) if the loading were spread uniformly over all water to give equal concentration in all of these discharges. This, then, is the driving force for Harbour water quality; if significant dilution, biochemical reaction, or sediment uptake occurs, then the observed Harbour concentration would be much less. If for example, the lake concentration is negligible, then exchange would dilute the average inflow concentration by approximately one fifth ($1/5$). Consider then iron and phenol. As the ratio of Harbour concentration to inflow concentration is much less than 0.2, then there is obviously significant modification of these two materials in the Harbour - in the case of phenol, rapid oxidation by bacteria to relatively harmless end products while for iron, accumulation in the sediments is the ultimate sink.

These material budgets provide a way for estimating short term changes in the hydraulics of the Harbour, when conservative materials are employed. Such conservative materials include total dissolved solids, chlorides, and transport of heat into the hypolimnion. A conservative material is one which does not undergo chemical reactions or is affected by biological processes; that is, it is only affected by physical processes. Based upon literature evidence, measurements

TABLE 6

PARAMETER	AVERAGE INFLOW CONCENTRATION *	AVERAGE HARBOUR CONCENTRATION	AVERAGE LAKE CONCENTRATION
TP	0.820 mg/L	0.075	0.03
SP	0.320	0.011	0.01
TKN	24.6	2.05	
NH ₃	19.0	1.6	0.3
NO ₃	1.7	0.93	0.06
TN	26.0	3.6 (TKN + NO ₃)	0.4
TOC	26	4	
COD	120	20	2
BOD ₅	20	4	1
SS	160		-
TDS	670	266	220
Cl	124	61	31
PHENOL	0.23	0.001	N.D.
CYANIDE	1.7	0.01	N.D.
OIL & GREASE	2.5	0.1	N.D.
H ⁺	6.0x10 ⁻⁸ Moles/L (pH = 7.22)	1.58 x 10 ⁻⁸ (pH = 7.8)	6.3 x 10 ⁻⁹ (pH = 3.2)
Fe	47	0.3	N.D.
Cu	0.18	0.02	N.D.
Pb	0.055	0.09	N.D.
Zn	1.4	0.1	N.D.
Cd	0.005	0.01	N.D.
As	0.01	0.001	N.D.
Mn	0.8	0.09	N.D.
Cr	0.16	0.02	N.D.
Ni	-	0.02	N.D.

* Average concentration resulting from all surface streams, stormwater outfalls and wastewater treatment plants (= Annual Loading / Total Hydraulic Flow Rate)



Exchange Flow Model for Hamilton Harbour

Figure 4

of currents in the ship canal, and material budgets for a few conservative materials, it is concluded that Figure 4 gives the best representation of the gross physics of the Harbour during summer stratification (22).

During stratification, a warm water layer ($21-24^{\circ}\text{C}$, the epilimnion) overlies colder denser bottom water ($11-14^{\circ}\text{C}$, the hypolimnion). This stratification is analogous to the more familiar thermal inversion in the atmosphere (e.g. hot air in the city coming off of approximately the mountain crest and typically being overlain by colder air pushed on by a front). Little transport of air pollutants occurs through this inversion layer, preventing their escape and when conditions are bad enough, (i.e. the Air Pollution Index is high enough), industry must lower production. Similar little transport occurs through the thermocline. There is a two way exchange flow between the Harbour and the Epilimnion (αEQout) and a smaller two way exchange flow across the thermocline ($\text{KTH} \times \text{ATH}$) due to diffusion. In addition, periodic episodes bring cold bottom water from Lake Ontario into the Harbour hypolimnion (αHQout) which then displaces hypolimnetic water into the epilimnion, and displacing epilimnetic water into the lake.

Estimates of the weekly variation of αE (=Epilimnetic Exchange Flow Rate/the Land Based Hydraulic Inflow Rate) and αH (=Lake Water Intrusion rate into the Hypolimnion/Land Based Hydraulic Inflow Rate) are given in Table 7. The corresponding hydraulic inflow rates (from streams, stormwater overflows and wastewater treatment plant P discharges) are given on the last column. For 1977, these figures suggest that αE varies from 1.4 to 5 over the year. Compare these weekly values for αE to those annual estimates for α for 1967-1975 in Table 4. This comparison shows that in addition to annual variations, there are monthly variations of the same order of magnitude. The Harbour is truly a very dynamic body of water.

TABLE 7 Estimated Values for α_E and α_H (K = week, L = month.
Year is considered to begin on June 1 for year)

DATA FOR 1977

α_E	α_H						
K=1	ALPHE= 1.4	ALPHH= 0.0	KTH= .6	L= 1	QIN= .45E+06		
K=2	ALPHE= 1.4	ALPHH= 0.0	KTH= .1	L= 1	QIN= .45E+06		
K=3	ALPHE= 1.4	ALPHH= 2.0	KTH= .1	L= 1	QIN= .45E+06		
K=4	ALPHE= 1.4	ALPHH= 2.0	KTH= .1	L= 1	QIN= .45E+06		
K=5	ALPHE= 1.4	ALPHH= 2.0	KTH= .7	L= 1	QIN= .45E+06		
K=6	ALPHE= 3.0	ALPHH= 2.0	KTH= .1	L= 2	QIN= .40E+06		
K=7	ALPHE= 3.0	ALPHH= 2.0	KTH= .1	L= 2	QIN= .40E+06		
K=8	ALPHE= 3.0	ALPHH= 2.0	KTH= .1	L= 2	QIN= .40E+06		
K=9	ALPHE= 3.0	ALPHH= 2.0	KTH= .1	L= 2	QIN= .40E+06		
K=10	ALPHE= 4.0	ALPHH= 2.0	KTH= .1	L= 3	QIN= .45E+06		
K=11	ALPHE= 4.0	ALPHH= 2.0	KTH= .1	L= 3	QIN= .45E+06		
K=12	ALPHE= 4.0	ALPHH= 4.0	KTH= .1	L= 3	QIN= .45E+06		
K=13	ALPHE= 4.0	ALPHH= 4.0	KTH= .1	L= 3	QIN= .45E+06		
K=14	ALPHE= 5.0	ALPHH= 2.0	KTH= .05	L= 4	QIN= .89E+06		
K=15	ALPHE= 5.0	ALPHH= 2.0	KTH= .05	L= 4	QIN= .89E+06		
K=16	ALPHE= 5.0	ALPHH= 0.0	KTH= .05	L= 4	QIN= .89E+06		
K=17	ALPHE= 5.0	ALPHH= 0.0	KTH= .05	L= 4	QIN= .89E+06		
K=18	ALPHE= 5.0	ALPHH= 0.0	KTH= .1	L= 4	QIN= .89E+06		
K=19	ALPHE= 5.0	ALPHH= 0.0	KTH= .1	L= 5	QIN= .11E+07		
K=20	ALPHE= 5.0	ALPHH= 0.0	KTH= .7	L= 5	QIN= .11E+07		
K=21	ALPHE= 5.0	ALPHH= 0.0	KTH= .7	L= 5	QIN= .11E+07		
K=22	ALPHE= 5.0	ALPHH= 0.0	KTH= .7	L= 5	QIN= .11E+07		
K=23	ALPHE= 1.4	ALPHH= 0.0	KTH= .7	L= 6	QIN= .95E+06		
K=24	ALPHE= 1.4	ALPHH= 0.0	KTH= .7	L= 6	QIN= .95E+06		
K=25	ALPHE= 1.4	ALPHH= 0.0	KTH= .7	L= 6	QIN= .95E+06		
K=26	ALPHE= 1.4	ALPHH= 0.0	KTH= .7	L= 6	QIN= .95E+06		
K=27	ALPHE= 1.4	ALPHH= 0.0	KTH= .7	L= 7	QIN= .15E+07		
K=28	ALPHE= 1.4	ALPHH= 0.0	KTH= .7	L= 7	QIN= .15E+07		
K=29	ALPHE= 1.4	ALPHH= 0.0	KTH= .7	L= 7	QIN= .15E+07		
K=30	ALPHE= 1.4	ALPHH= 0.0	KTH= .7	L= 7	QIN= .15E+07		
K=31	ALPHE= 1.4	ALPHH= 0.0	KTH= .7	L= 7	QIN= .15E+07		
K=32	ALPHE= 1.4	ALPHH= 0.0	KTH= .7	L= 8	QIN= .55E+06		
K=33	ALPHE= 1.4	ALPHH= 0.0	KTH= .7	L= 8	QIN= .55E+06		
K=34	ALPHE= 1.4	ALPHH= 0.0	KTH= .7	L= 8	QIN= .55E+06		
K=35	ALPHE= 1.4	ALPHH= 0.0	KTH= .7	L= 8	QIN= .55E+06		
K=36	ALPHE= 1.4	ALPHH= 0.0	KTH= .7	L= 9	QIN= .55E+06		
K=37	ALPHE= 1.4	ALPHH= 0.0	KTH= .7	L= 9	QIN= .55E+06		
K=38	ALPHE= 1.4	ALPHH= 0.0	KTH= .7	L= 9	QIN= .55E+06		
K=39	ALPHE= 1.4	ALPHH= 0.0	KTH= .7	L= 9	QIN= .55E+06		
K=40	ALPHE= 1.4	ALPHH= 0.0	KTH= .7	L= 10	QIN= .19E+07		
K=41	ALPHE= 1.4	ALPHH= 0.0	KTH= .7	L= 10	QIN= .19E+07		
K=42	ALPHE= 1.4	ALPHH= 0.0	KTH= .7	L= 10	QIN= .19E+07		
K=43	ALPHE= 1.4	ALPHH= 0.0	KTH= .7	L= 10	QIN= .19E+07		
K=44	ALPHE= 1.4	ALPHH= 0.0	KTH= .7	L= 10	QIN= .19E+07		
K=45	ALPHE= 1.4	ALPHH= 0.0	KTH= .7	L= 11	QIN= .19E+07		
K=46	ALPHE= 1.4	ALPHH= 0.0	KTH= .7	L= 11	QIN= .19E+07		
K=47	ALPHE= 1.4	ALPHH= 0.0	KTH= .7	L= 11	QIN= .19E+07		
K=48	ALPHE= 1.4	ALPHH= 0.0	KTH= .7	L= 11	QIN= .19E+07		
K=49	ALPHE= 1.4	ALPHH= 0.0	KTH= .7	L= 12	QIN= .55E+06		
K=50	ALPHE= 1.4	ALPHH= 0.0	KTH= .7	L= 12	QIN= .55E+06		
K=51	ALPHE= 1.4	ALPHH= 0.0	KTH= .7	L= 12	QIN= .55E+06		
K=52	ALPHE= 1.4	ALPHH= 0.0	KTH= .7	L= 12	QIN= .55E+06		
K=53	ALPHE= 0.0	ALPHH= 0.0	KTH= .7	L= 13	QIN= .22E+03		

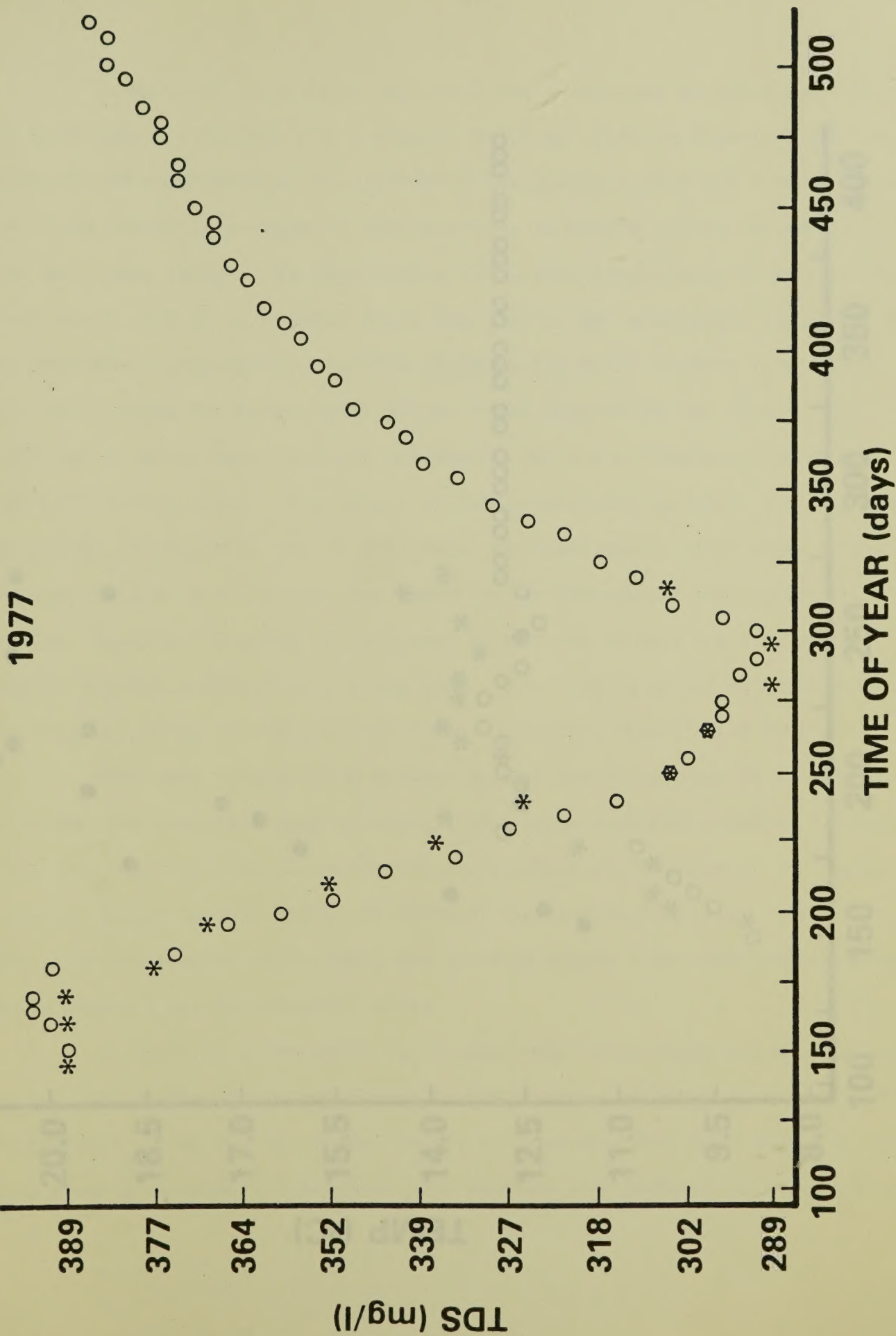


Figure 5 Observed (*) and Predicted (O) Values for Epilimnetic TDS, 1977

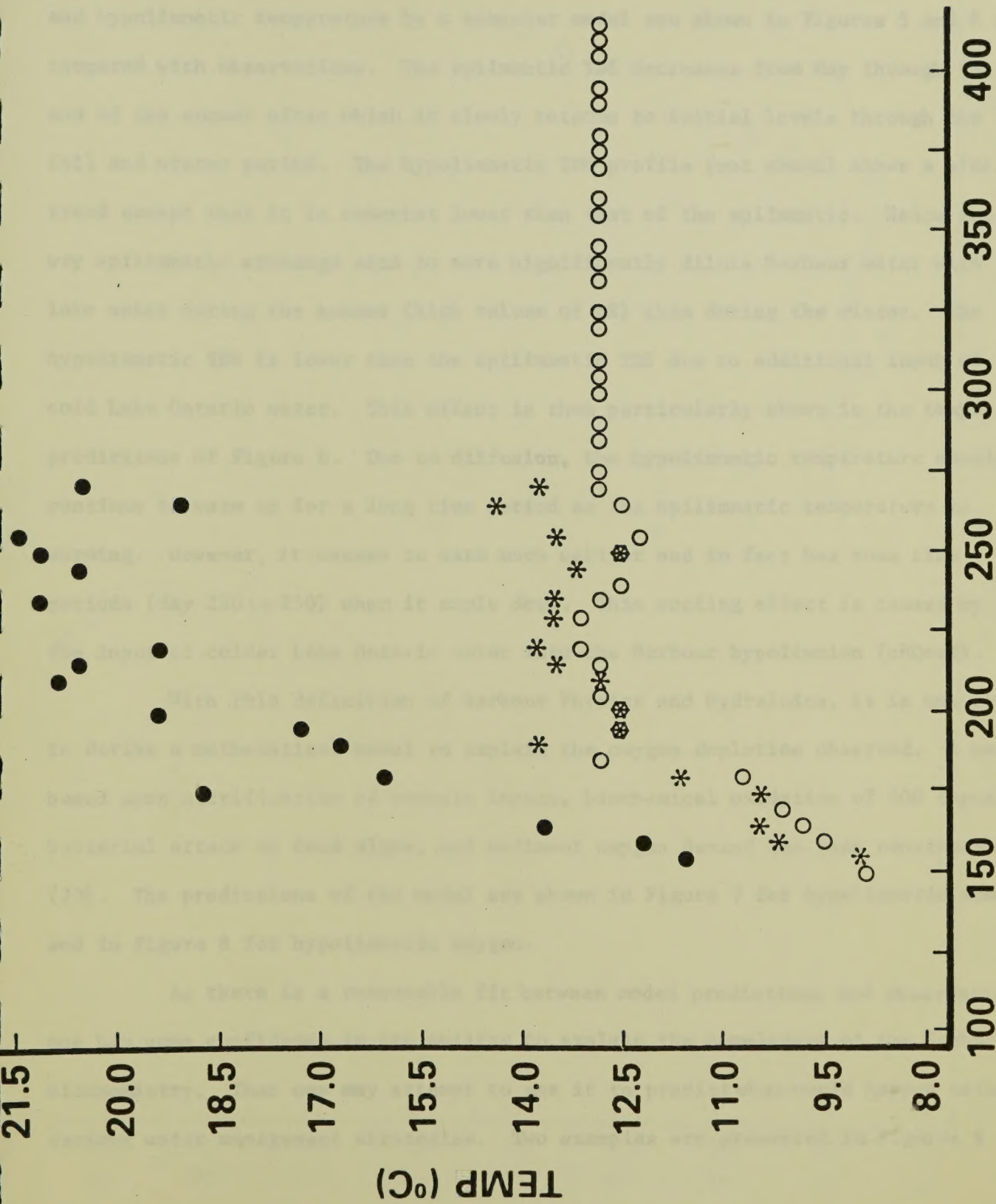


Figure 6

Observed Epilimnetic (●), Hypolimnetic (*) and Predicted Hypolimnetic (○) Values of Temperature, 1977

Using these value of αE , αH , etc., the predictions of epilimnetic TDS and hypolimnetic temperature by a computer model are shown in Figures 5 and 6 and compared with observations. The epilimnetic TDS decreases from May through to the end of the summer after which it slowly returns to initial levels through the fall and winter period. The hypolimnetic TDS profile (not shown) shows a similar trend except that it is somewhat lower than that of the epilimnetic. Hence the two way epilimnetic exchange acts to more significantly dilute Harbour water with lake water during the summer (high values of αE) than during the winter. The hypolimnetic TDS is lower than the epilimnetic TDS due to additional input of cold Lake Ontario water. This effect is then particularly shown in the temperature predictions of Figure 6. Due to diffusion, the hypolimnetic temperature should continue to warm up for a long time period as the epilimnetic temperature is warming. However, it ceases to warm much earlier and in fact has some time periods (day 220 to 250) when it cools down. This cooling effect is caused by the input of colder Lake Ontario water into the Harbour hypolimnion (αH_{Qout}).

With this definition of Harbour Physics and Hydraulics, it is now possible to derive a mathematical model to explain the oxygen depletion observed. A model based upon nitrification of ammonia inputs, biochemical oxidation of BOD inputs, bacterial attack on dead algae, and sediment oxygen demand has been constructed (23). The predictions of the model are shown in Figure 7 for hypolimnetic ammonia and in Figure 8 for hypolimnetic oxygen.

As there is a reasonable fit between model predictions and observations, one has some confidence in its ability to explain the complexity of the Harbour's biochemistry. Then one may attempt to use it to predict what would happen using various water management strategies. Two examples are presented in Figures 9 and 10.

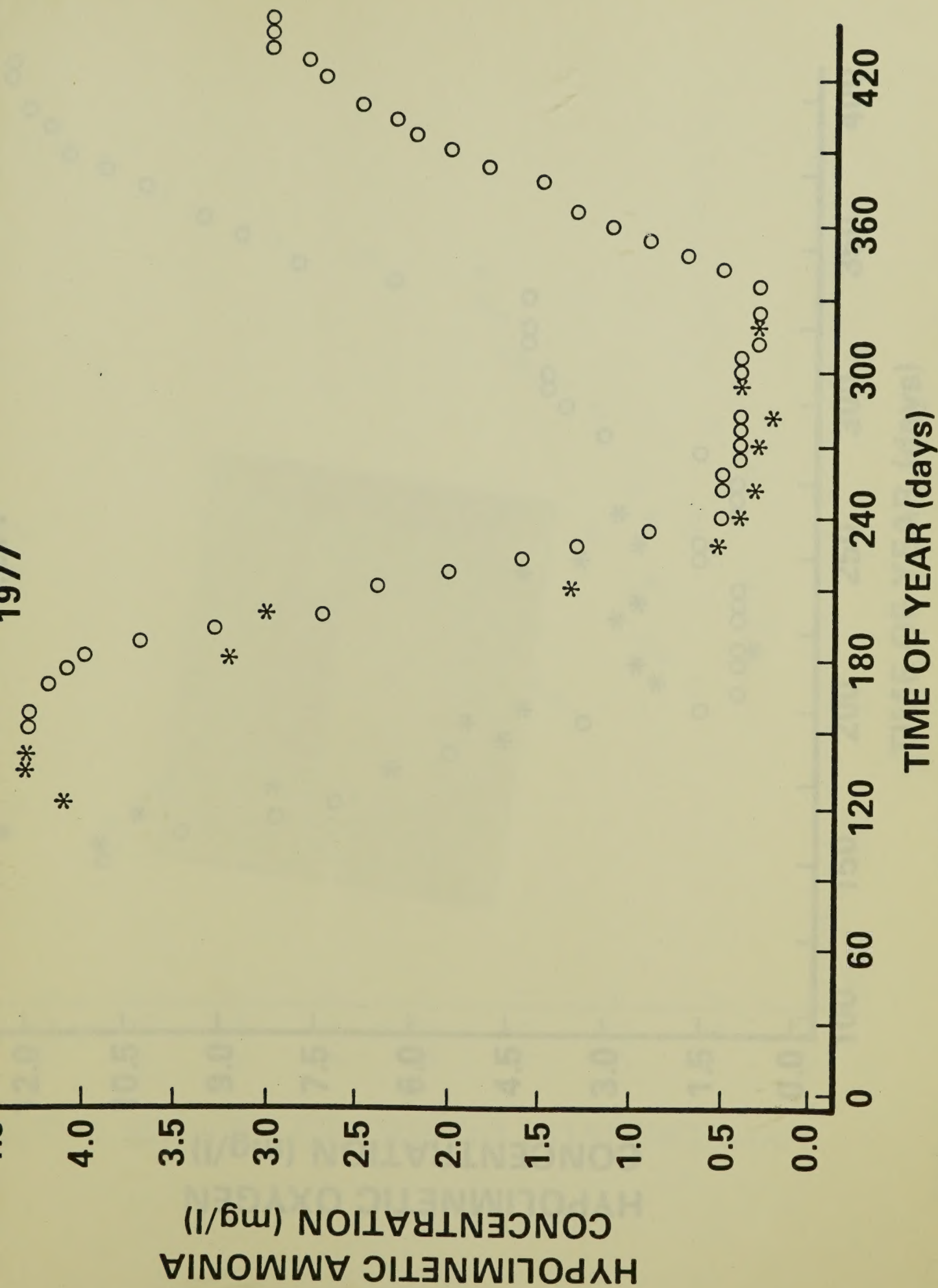


Figure 7

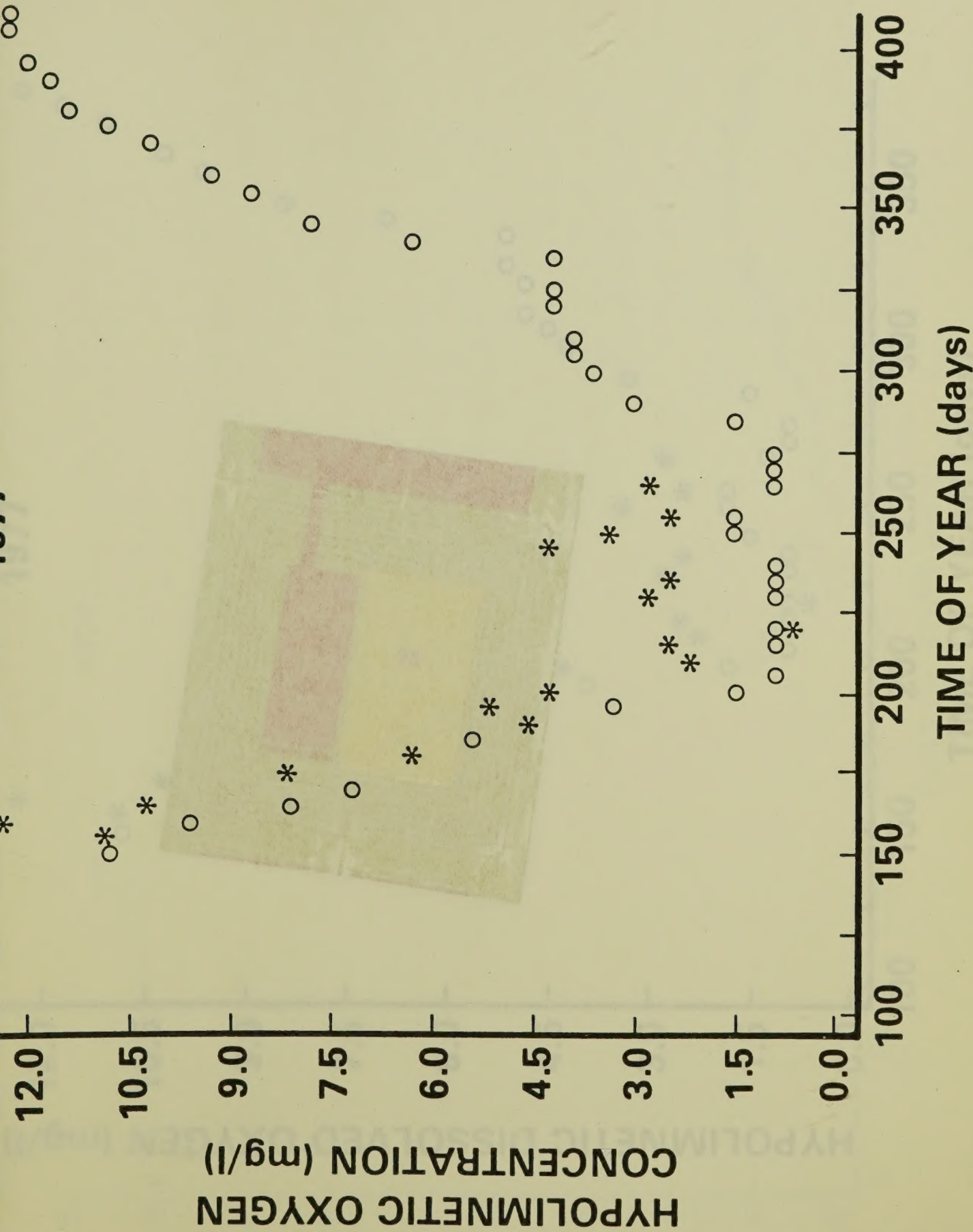


Figure 8

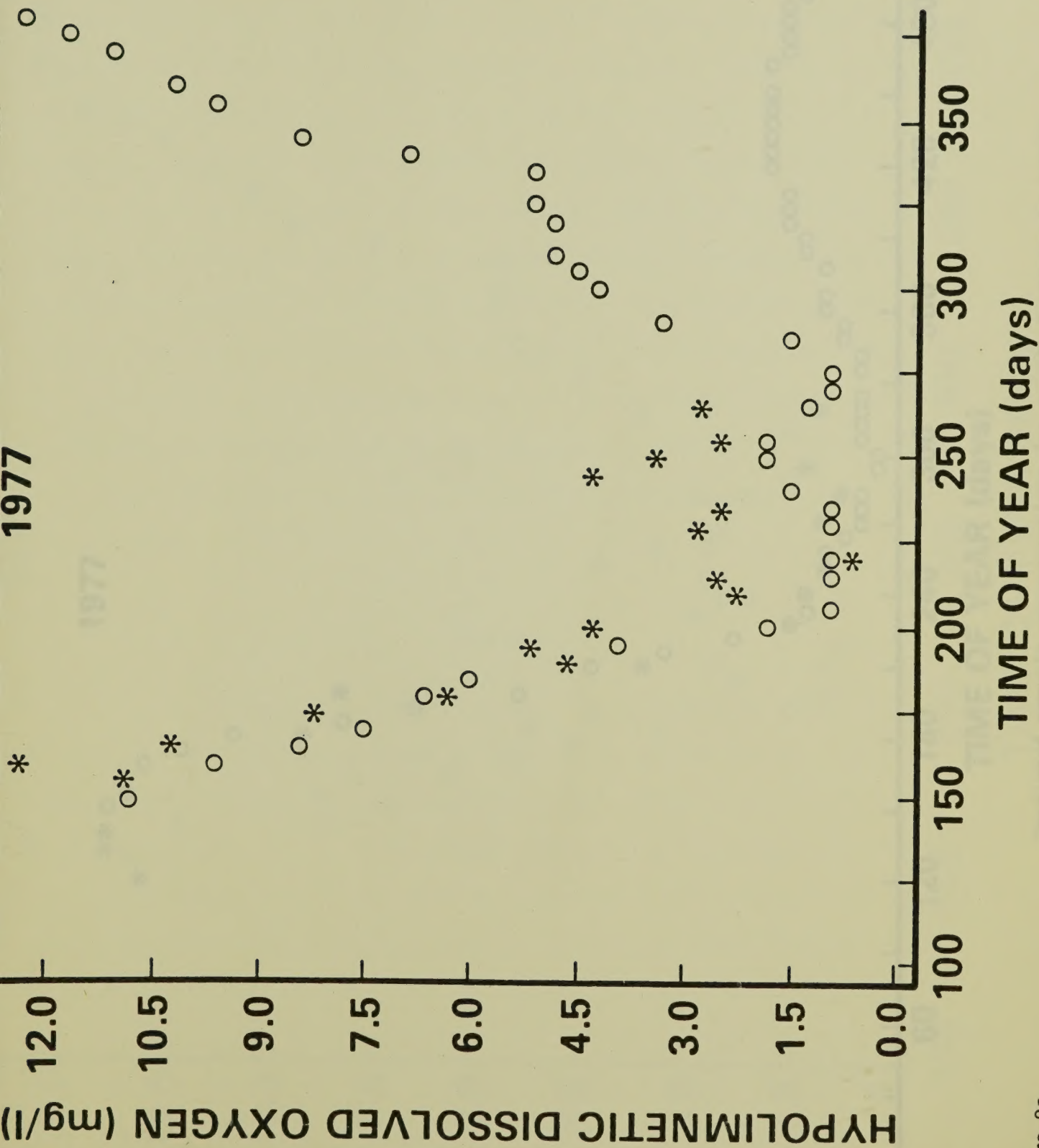
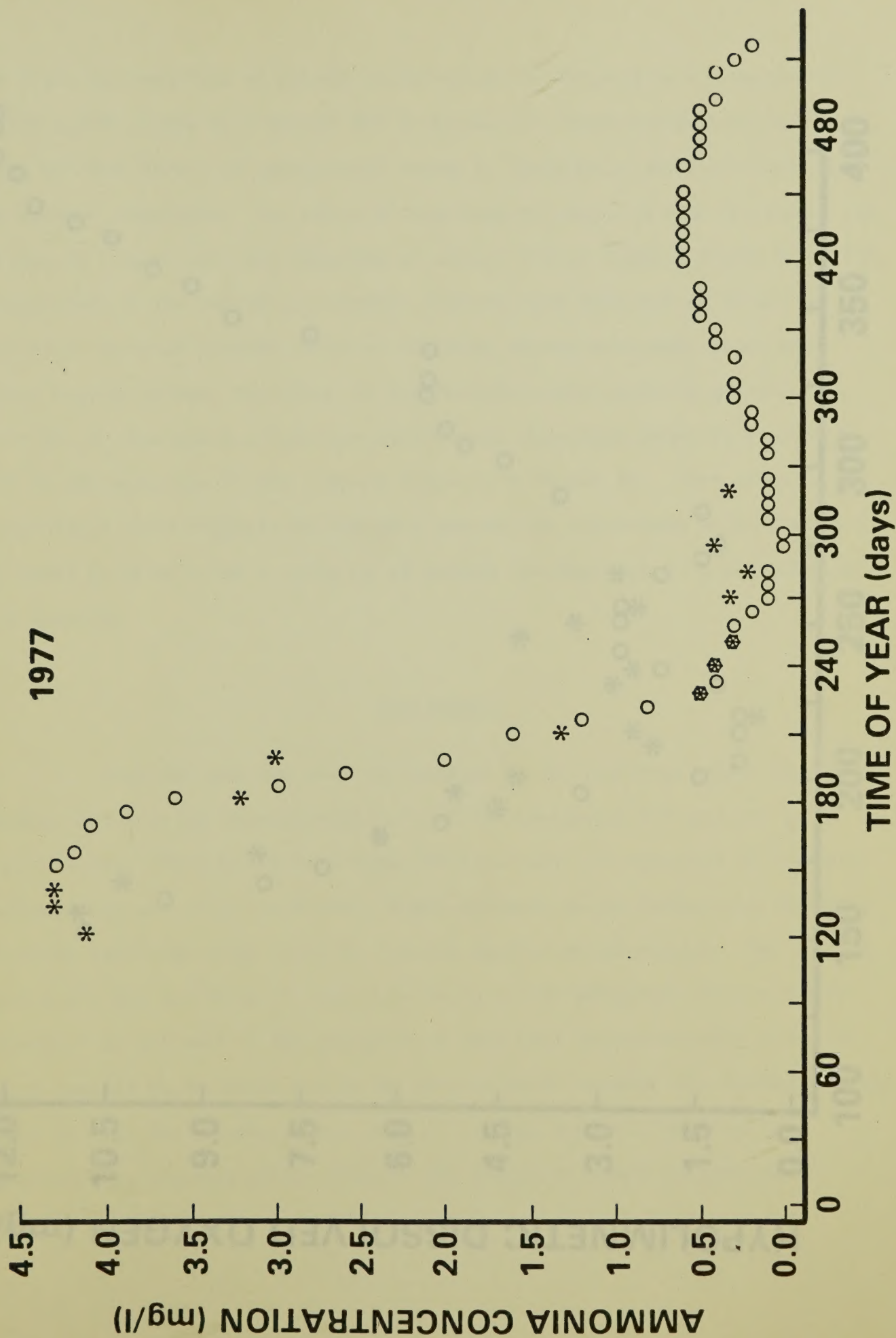


Figure 9a

Productions of hypolimnetic dissolved oxygen resulting from an 80% reduction in ammonia inputs.



Predicted ammonia concentrations for an 80% decrease in inputs.

Figure 9b

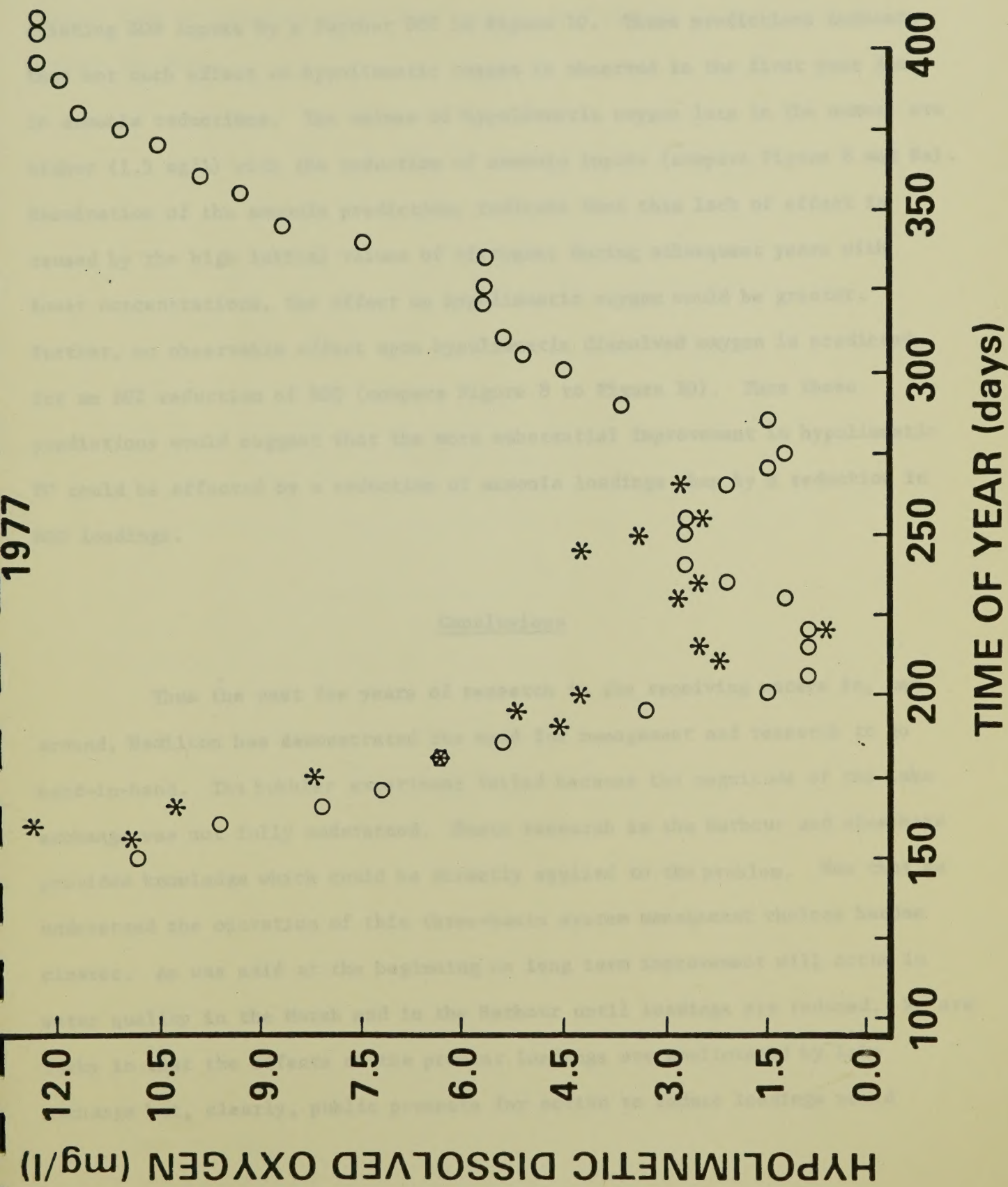


Figure 10

Predictions of hypolimnetic dissolved oxygen resulting from an 80% decrease in BOD loadings

In Figure 9, reduction of ammonia inputs by 80% is compared to a reduction of existing BOD inputs by a further 80% in Figure 10. These predictions indicate that not much effect on hypolimnetic oxygen is observed in the first year due to ammonia reductions. The values of hypolimnetic oxygen late in the summer are higher (1.5 mg/l) with the reduction of ammonia inputs (compare Figure 8 and 9a). Examination of the ammonia predictions indicate that this lack of effect is caused by the high initial values of nitrogen; during subsequent years with lower concentrations, the effect on hypolimnetic oxygen would be greater. Further, no observable effect upon hypolimnetic dissolved oxygen is predicted for an 80% reduction of BOD (compare Figure 8 to Figure 10). Then these predictions would suggest that the more substantial improvement in hypolimnetic DO could be effected by a reduction of ammonia loadings than by a reduction in BOD loadings.

Conclusions

Thus the past few years of research in the receiving waters in, and around, Hamilton has demonstrated the need for management and research to go hand-in-hand. The bubbler experiment failed because the magnitude of the Lake exchange was not fully understood. Basic research in the Harbour and elsewhere provided knowledge which could be directly applied to the problem. Now that we understand the operation of this three-basin system management choices become clearer. As was said at the beginning no long term improvement will occur in water quality in the Marsh and in the Harbour until loadings are reduced. We are lucky in that the effects of the present loadings are ameliorated by Lake exchange but, clearly, public pressure for action to reduce loadings would

have been much greater if the full expression of the loadings had occurred. Either that or commuters would have been content to walk in from Burlington across the Bay.

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GENERAL CONSIDERATIONS CONCERNING THE SANITARY CONDITION OF BURLINGTON BAY

This sanitary survey of the waters of Burlington Bay began in 1934 to assess the impact of discharging sewage effluent into the Bay water.

A great deal of data has accumulated over the past 46 years. This report, prepared for the "Environment 80 Conference" held in Hamilton in November, 1980. It is not intended that this report should be a scientific treatise but instead a report that can be easily understood by the general public.

The following conclusions can be reached by examining the data.

Bacteriological Assessment

1. In the past, from 1934-1960, Burlington Bay was grossly polluted with coliform bacteria.
2. With the construction of a primary sewage treatment plant in 1964 and the secondary plant in 1972, the coliform bacteria concentration began to decrease dramatically.
3. In the past decade, from 1970-1979, the coliform organisms have decreased 90% from 1934-1940,
63% from 1950-1960,
39% from 1960-1970.
4. The overall reduction in coliform bacteria has reduced from 112,100 in 1934-1940 to 7,200 in 1979; this is a reduction of 94%.

General Considerations

The construction of the Hamilton sewage treatment plant has had a dramatic effect upon the reduction of the coliform bacteria in the Bay waters.

The volume of treated sewage effluent is increasing markedly, eventually a substantial proportion of the Bay water will be treated effluent.

The treated effluent will contain substantial concentrations of nitrogen compounds which could in the future contribute to the possibility of large algae growths. This possibility will increase when industrial effluents are also improved by the removal of elements which are now toxic to biological organisms.

Efforts should be directed towards increasing the total volume of water in the Bay as well as attempting to reduce nitrogen compounds in the influents to the Bay.

Chloride Ion Concentration Assessment

1. The chloride ion has increased 210% or three-fold since 1934.
2. The current concentration level of 65 p.p.m. is not excessive.
3. The rate of increase of chloride ion has not yet reached a steady state, a correlation coefficient of 94.1% confirms this fact.

Nitrate-Nitrogen Assessment

1. Nitrate-nitrogen is a measure of the total nitrogen loading which has remained in the Bay waters.
2. The nitrate-nitrogen has increased six-fold or 84% since 1948.
3. The concentration of nitrate is still slowly increasing in the Bay waters as indicated by an extremely good correlation coefficient of 79.8%. The rate of change of increase in recent years has not changed.

Phosphorus Assessment

1. Phosphorus concentrations have never been a major problem in Burlington Bay.
2. Since the restriction on the use of phosphorus compounds came into effect the concentrations of phosphate has dropped to very low levels.

INTRODUCTION

Burlington Bay has had a very long history of being somewhat famous in Canada. The fame in which this body of water has revelled began with its discovery by LaSalle in the year 1669 and culminated fairly recently when a cabinet minister attempted to swim across the Bay to prove that it was not polluted.

At the time of its discovery by LaSalle, Burlington Bay was called Lake Macassa by the Attiwandaronk Indians who inhabited its shores. Their name for this body of water translates into "The Lake of Shining Waters"; this descriptive name belies its appearance to-day.

Descriptions of Lake Macassa by LaSalle indicates that this beautiful lake was teeming with fish and its shores abounded with wild life. Certainly it had helped to support the indigenous population for centuries. Since the name was changed to Burlington Bay and the population changed from indigenous to an immigrant population, the characteristics of this beautiful body of water have changed drastically. It now supports a completely different type of indigenous population and a much larger one.

Macassa Lake was throughout its early history, separated from Lake Ontario by a sand bar. At times the sand bar would be a few inches under water and at other times it would be above the water level thus creating a small lake.

The next time that Burlington Bay was mentioned in history, was during the war of 1812-1814. At that time three British Man-of-War were being pursued by an American Naval Force which outnumbered them. Discretion being the better part of valour, the British Captain with considerable effort had his ships physically hauled through a very shallow channel which at times prevailed across through the sand bar which normally separated Lake Macassa from

Lake Ontario. The ships were able to hide out from the American forces. Presumably Lake Macassa was ringed by a heavy forest which obscured the American Naval Forces' view from Lake Ontario.

The earliest centre of commerce in the vicinity of Lake Macassa was at Dundas, Ontario. It thrived because it was on a direct land path from York (now Toronto) to south western Ontario. However, shortly after the War of 1812-1814, the town of Hamilton came into existence and it achieved city status in the year 1848.

From this time on, Lake Macassa gradually ceased to be an isolated beautiful lake and became the catalyst which caused the City of Hamilton to grow into an industrial centre.

During the early days of Hamilton, in the middle of the 19th century, Lake Macassa provided the citizens of Hamilton with many benefits; these included efficient transportant to the surrounding communities, harvesting of ice for the long hot summers, fish both for sport and as a major food supply and an abundance of game, including wild fowl.

While the harbour shared its natural bounty with the citizens who lived upon its shores, the two existed compatibly until the area became an industrial centre at the end of the 19th century.

Hamilton was now becoming a centre of commerce for the area because of the excellent harbour which Lake Macassa provided and offered shelter from Lake Ontario. Because of this industry began to flourish in the area. The population began to increase rapidly with the influx of an immigrant population from Ireland and Scotland.

The first blemish inflicted upon the area occurred when the immigrant population brought with it a cholera epidemic in the year 1832 and again in 1854. The epidemic spread, inflicting many casualties on the population. Attempts were made to improve sanitary conditions, however, the epidemic eventually ran its course.

Early in the 1900's fecal matter could be found floating in the eastern end of Burlington Bay. Perhaps the ultimate pollution of the harbour was foreseen by the City Engineer fifty years earlier because he began to persuade the politicians of the day to obtain Hamilton's drinking water from Lake Ontario.

After considerable debate and numerous surveys by consulting engineers on 26 October 1859, a five million gallons per day capacity pumping station was constructed and located between the far eastern end of the Bay and Lake Ontario, on what is now Woodward Avenue, to obtain drinking water from Lake Ontario. It was indeed fortunate for the citizens of Hamilton that one of the alternate sources of water supply such as Burlington Bay was not chosen.

The acceleration of the poor water quality in Burlington Bay began in the late 1800's and culminated in the banning of swimming by the Chief Medical Officer, in any of its waters, in 1930.

Although there are some logical reasons and to some extent an economical justification for the increasingly poor water quality in Burlington Bay, it can by no means justify the wholesale pollution which occurred.

The initial industrial growth period in Hamilton from the year 1890 to about 1914 occurred without a great deal of concern about the harbour waters. For it was very large compared to the industry now beginning to locate on its shores. About the time that everyone should have been concerned the First World War occurred and by then the only thing that mattered was increased production for the war effort.

After the cessation of hostilities in 1918 and normalcy began to return, more attention in the community was paid to rehabilitation toward a peace time economy than to matters of the environment. No sooner had some semblance of normalcy been restored in the community than a world wide depression occurred. For the

next 10 years, there was extremely high unemployment and virtually no money for such frills as the protection of our environment.

Around the same time as Canada was recovering from the major economic recession of the 1930's, once again the world was plunged into a second world war in 1939. Of course during this major conflict complete emphasis was placed upon production for war effort and after the end of the war in 1945 a transition from a war time economy to a peace time economy took several years.

It wasn't until the mid 1950's that the Provincial Government of Ontario began to seriously examine the consequences of ignoring environmental matters. From that time onward, legislation was forthcoming from the provincial legislature concerning the abatement of pollution of our environment.

In 1956 City Council formed a new department within its administrative system called the Municipal Laboratories. This new department had among many of its responsibilities that of enforcing an air pollution by-law.

The first Director of this department, Mr. D.H. Matheson had begun his career with the City of Hamilton as a waterworks chemist in 1933. At that time he had the foresight to realize that Burlington Bay could become polluted.

The City Engineer in 1934, W.L. McFaul, directed the Chief Chemist of the sewage plant, Mr. W. Watmough, to conduct a bacteriological study of Burlington Bay. The date of that directive was 21 August 1934. The first survey of the Bay was carried out the very next day on the 22 August 1934, by Mr. W. Watmough.

A few years later Mr. Watmough and Mr. Matheson collaborated on the sanitary survey of the waters of Burlington Bay. Mr. Matheson increased the scope of the survey by determining a few more pollution parameters.

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inspector in 1931. At that time he had the knowledge for training and
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A few years later Mr. Harrison and Mr. McKay collaborated
on the sanitary survey of the waters of Burlington Bay. Mr. Harrison
extended the scope of the survey by determining a few more points
this summer.

When Mr. D.H. Matheson assumed increased responsibilities for all laboratory operations within the City of Hamilton, he intensified the annual sanitary survey. In 1958 he published a report entitled "A Consolidated Report on Burlington Bay - 1958".

Mr. A.V. Forde was appointed Director of the Laboratory upon the retirement of Mr. Matheson. Under the new Director the survey continued and although the Laboratory is now under the Engineering Department of the Hamilton-Wentworth Region, the survey is continuing.

Since the most often asked question about Burlington Bay is "Is the harbour getting more polluted or is it improving?", it was decided to present another report which would address itself to that question.

This report represents all of the data collected by the Municipal/Regional Laboratories from 1934 to 1979.

A.V. Forde

Director of Regional Laboratories
Department of Regional Engineering

When Mr. D.A. Macdonald assumed the position of Director of the Laboratory for all laboratory operations within the City of Montreal, he immediately initiated the annual survey survey. In 1955 he published a report entitled "A consolidated report on the survey 1955-1956".

Mr. A.V. Ford was appointed Director of the Laboratory in 1956. Under the supervision of Mr. Macdonald, under the new Director the survey continued and although the Laboratory is now under the management of the Montreal-Metro Area, the survey is continuing.

Since the most often asked question about the survey is "Is the survey still being carried on?" it is important to say that the survey is still being carried on and that it is still being carried on in the same manner as in the past.

This report represents all of the data collected by the Montreal-Metro Area Laboratory from 1955 to 1956.

A.V. Ford

Director of Regional Laboratories
Department of Regional Laboratories

THE SANITARY SURVEY - GENERAL

Chapter No. 1

Since 1934, when Mr. W. McFaul, the City Engineer issued the directive to Mr. Watmough, the chemist in charge of sewage treatment plant to conduct a Bacteriological study of Burlington Bay, data has been collected annually.

There are a few rather lengthy periods during which little or no data was collected. One of these coincided with the War of 1939-1945. Another period when data was not collected on a regular basis was from about 1948 until 1956.

In spite of this slight deficiency of data, there is sufficient information to enable one to observe the rate of concentration of certain parameters.

Initially Mr. Watmough was interested in the bacteriological aspect of the waters of Burlington Bay. However, a few years later, when Mr. D.H. Matheson, who was the chief chemist and bacteriologist of the Hamilton water purification plant, was asked to take part in the survey, together they decided to investigate some of the chemical parameters of the water.

In 1956 the Department of Municipal Laboratories was established. It was charged with the responsibility of controlling pollution in the Hamilton area. The author of this paper, A.V. Forde, joined the staff at that time. Now with an increased staff the department was able to devote a much greater effort to the conditions of the harbour waters on a routine basis. For that reason the data from 1956 to present 1980 has been continuous. Furthermore the number of parameters studied was increased to fifteen.

This survey of the waters of Burlington Bay (Hamilton

Harbour) took place over 46 years. During that period of time there have been many changes in analytical techniques. However, each time a more advanced technique was adopted, very careful comparative analyses were made in order to ensure that good correlation existed between the old and new methods.

About 1956-1957 the laboratory made the change from the M.P.N. method of determining the coliform bacteria to the membrane filter technique. Attempts were made to correlate the two methods. It was found that individual samples did not have a very good correlation, however when averages were examined over a long period of time the correlation was quite good. Since this paper deals with monthly and annual averages, the correlation between data prior to 1957 and after is deemed to be within the limits of experimental error.

Although improved analytical techniques were employed as the survey progressed, these methods served to improve the statistics of the analyses but essentially gave similar results as earlier techniques.

It can be said that the data and the statistical methods used to examine the 46 years of data are quite reliable. It is unfortunate however that all fifteen parameters had not been studied continuously since 1934. Nevertheless there is sufficient information to lend considerable reliability to the trends observed during this survey. This is particularly the case for B. Coli, F.Coli, Chlorides, Nitrates and Phosphates.

During the 46 years of sampling the location of the sampling points were gradually reduced in number. In more recent years a well defined numbering system evolved. It was therefore necessary to re-assign this numbering system to the early data. This involved discarding data from other sections of the Bay. For example, during the early years of sampling it had been the practice to sample around the perimeter of the shore line every 1/4 of a mile or so. Since very

little difference in measured values occurred from one sample point to the next, there was virtually no affect upon the overall analyses by choosing one sampling location over another.

The 46 years of data was processed to obtain monthly averages and annual averages for each sampling location and for each month. All of this information was then stored in a radio shack computer model TRS 80 for statiscal evaluation and graphical representation.

Chapter No. 2

THE WATERSHED AND BURLINGTON BAY

The ice age and the resulting melting of the glaciers in the Western end of Lake Ontario directly affected the geology and the geography of the drainage basin of Burlington Bay.

At one time a large interglacial river following the course of a deep gorge running from Lake Ontario through what is now known as the Dundas Valley to the present site of Port Stanley drained the waters of Lake Ontario (then called Lake Iroquois) into the Mississippi River.

As the melt waters receded the gorge became filled with glacial deposit, except for the present Dundas Valley. At the same time a spit of land was formed isolating the Bay from Lake Ontario.

Until the year 1832 Burlington Bay, formerly known as Lake Macassa, was completely isolated from Lake Ontario by the sand spit. There was a small opening between the Bay and the Lake which was so shallow that in periods of low water was practically non-existent.

In 1832 an artificial cut was made across the sand spit

connecting Burlington Bay with Lake Ontario. This cut required considerable dredging and maintenance and was replaced by a larger cut in 1850 at the present site of the Burlington Canal.

Drainage Area

The total drainage area of Burlington Bay is about 190 square miles. There are three major creeks which drain the area, these are - Grindstone Creek which drains the Waterdown area to the north of the Bay, Spencer Creek which drains the Dundas Valley or western sector, and Red Hill Creek which drains the King's Forest area or the south and eastern sector of the watershed.

Table No. 1 lists the principal drainage areas of the watershed and the area which is drained.

About 54% of the watershed is drained into Cootes Paradise (the Marsh) before entering the Bay. The remaining 46% drains directly into the Bay, through Red Hill Creek and Grindstone Creek as well as run off from the City of Hamilton.

Run Off

The annual precipitation averages about 31 inches (86,000 million gals./yr.) per year. The amount of this precipitation which reaches the various streams depends upon a number of factors, about which precise information is not available. Some of these factors are the absorbency of the soil, the rate of rainfall, the evaporation rate and many others. Certain assumptions must be made in order to approximate the percent of the precipitation which may reach the various streams and ultimately the Bay.

Gore, Nasmith & Storrie (1) assumed the run off to be about 10 inches (1923) per year. Chapman & Putnam (2) estimated that the Grand River represents an equivalent of 11 inches of run off and that the Thames River flow represents a little over 12 inches

TABLE NO. 1

ANALYSES OF WATERSHED AREAS

<u>Watershed Region</u>	<u>Area</u>		<u>Percent of Watershed</u>
	<u>Sq. Miles</u>	<u>Sq. KM</u>	
Spencer Creek	76		40 %
Mineral Springs Creek	18		10 %
Rock Chapel Creek	8		4 %
Grindstone Creek	34		18 %
Red Hill Creek	24		12 %
City of Hamilton	30		16 %

Table No. 1 shows these calculations and expresses the

of run off. Therefore 10 inches of run off per year seems like a reasonable amount for the Burlington Bay drainage area.

This 10 inches per year of run off on the 190 sq. miles of watershed means that 28,000 million gallons of water finds its way into Burlington Bay each year. This amount is reasonably constant throughout the years and represents a fairly constant natural flow to the Bay.

The annual influent to the waters of Burlington Bay comes from two major sources, run off and treated sewage effluent. Because of increased population growth, particularly in the years following the second world war, sewage effluent has increased dramatically. This is illustrated in Table No. 2.

Since the annual run off to the Bay is fixed at about 28,000 million gallons and the volume of the Bay is approximately 68,000 million gallons, the treated sewage effluent is becoming a significant proportion of "Bay water".

It can be seen that in 1949 the run off and the total sewage flow to Burlington Bay amounted to 10,000 million gallons annually. Each of these sources represented about 14.7% of the total Bay volume. However by 1979, 30 years later the sewage effluent flow to the harbour was twice that of the run off and consequently the sewage effluent now makes up 39.1% of the composition of the harbour.

These facts can be illustrated in a more meaningful way if one looks at the throughput of the Bay. For example, the Bay contains 68,000 million gallons of water. Now if the annual run off and annual sewage effluent (the major source of water to the Bay) are added together, that volume can be used to calculate how long it would take to fill up the Bay (if it were empty!).

Table No. 3 shows these calculations and expresses the

TABLE NO. 2

ANNUAL SEWAGE EFFLUENT FLOW TO BURLINGTON BAY
(in millions of gallons)

Year	Hamilton- Wentworth Plant	Waterdown Plant	Dundas Plant	Burlington Plant	Total	Percent of Bay Volume
1949	10,000 (E)					14.7
1957	15,000 (E)					22.1
1958	15,000 (E)					22.1
1965	13,549			965	14,514	21.3
1966	13,252			1,111	14,363	21.1
1967	13,169			1,419	14,588	21.5
1968	16,019			1,365	17,384	25.6
1969	17,321			1,218	18,539	27.3
1970	17,906			2,227 (E)	20,133	29.6
1971	18,200			2,558 (E)	20,758	30.5
1972	19,074			2,948	22,022	32.4
1973	19,810			3,219 (E)	23,029	33.9
*1974	20,758		568	3,350 (E)	24,676	36.3
1975	19,252			3,443	22,695	33.4
1976	19,989			4,211 (E)	24,200	35.6
1977	20,420	100	637	4,542 (E)	25,699	37.8
1978	19,210	100	657	4,873 (E)	24,840	36.5
1979	20,173	100	629	5,684	26,586	39.1

E = estimated flow.

* = Regional Municipality of Hamilton-Wentworth imposed an sewer impost tax - this reduced the annual flow.

TABLE NO. 3

* THROUGHPUT OF BAY WATER VOLUMES

(Expressed in Months)

<u>Year</u>	<u>Throughput, in Months</u>
1949	21.5
1957	18.9
1958	18.9
1965	19.2
1966	19.3
1967	19.2
1968	18.0
1969	17.5
1970	17.0
1971	16.7
1972	16.3
1973	16.0
1974	15.4
1975	16.1
1976	15.1
1977	15.2
1978	15.4
1979	14.9

* = Based upon an approximate volume of the Bay
of 68,000 million gallons.

throughput in months (time required to fill a volume equal to the Bay). The information in Table No. 3 is related to how long water may be retained in the Bay before entering the lake.

Since the Bay acts as a oxidation pond it is desirable not to shorten the retention time of Bay water. However a shortening of the retention time is inevitable as population increases with a subsequent increase in sewage effluent flow. Since 1949 the retention time in the Bay has been reduced 30%.

It is evident that in the future an increasingly greater percentage of Burlington Bay water will be sewage effluent. At the same time as this will be occurring the rate of throughput to Lake Ontario will also be increasing. Based upon previous data and assuming a conservative estimate, by the year 2000 about 75% of the Bay water will be composed of sewage effluent. Also by the year 2000 the throughput to the lake will be further reduced to about 10 months.

These trends are based upon the present volume of harbour. The changes in throughput and composition would be altered if the harbour volume was to become reduced by deliberate land filling or by natural sediment deposition.

The loss of the fishing industry and the harvesting however were a direct result of a deterioration of the quality of water in the harbour. These changes were more easily accepted by the local inhabitants because transportation and technology gradually allowed for a changing life style.

Especially the nature of Burlington Bay have of necessity assumed the role of acting as a tertiary stage for the treatment facilities for the population in the area. For this reason it

Chapter No. 3

FUNCTIONS OF BURLINGTON BAY

Ever since the incorporation of the City of Hamilton during the early part of the 19th Century, Burlington Bay has provided a useful function to the area.

Initially, when Hamilton was a small settlement, the Bay provided transportation, recreation, a fishing industry and ice was harvested annually. However at the beginning of the 20th Century these more esthetic functions were gradually supplanted by an increasing number of commercial functions. The Bay became a useful harbour for shipping and its shoreline began to support commerce and industry. These new functions eventually dominated the scene so that the only esthetic function remaining is recreational boating.

In more recent years a new function for the Bay came to fore, that is, as a tertiary treatment pond for the sewage effluent from various municipalities on its shores.

Most of these changes have come about gradually and in a very subtle way. The loss of the Bay waters as a local transportation vehicle came about because of improved roads and the coming of the automobile. This loss was not the result of problems associated with the harbour but by a change in technology.

The loss of the fishing industry and ice harvesting however were a direct result of a deterioration of the quality of water in the harbour. These changes were more easily accepted by the local inhabitants because, transportation and technology gradually allowed for a changing life style.

Recently the waters of Burlington Bay have of necessity assumed the role of acting as a tertiary stage for the treatment facilities for the population in the area. For this reason it

becomes increasingly important to measure certain water quality parameters in order to ensure that this present function of the harbour waters do not become so overburdened that this function would cease to exist.

Since the beginning of the last century the water quality in the harbour has been deteriorating. The water quality in the harbour has been deteriorating since the beginning of the last century. The water quality in the harbour has been deteriorating since the beginning of the last century.

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The two objectives reported in this study are to determine the water quality in the harbour and to determine the water quality in the harbour. The water quality in the harbour has been deteriorating since the beginning of the last century.

Chapter No. 4

BACTERIOLOGICAL EXAMINATION OF BURLINGTON BAY

When examining the water quality of any surface water one immediately becomes concerned with the identification and enumeration of the bacteriological concentration.

Since the bacteriological study of Burlington Bay began about 1934, techniques for identifying and counting bacteria have changed considerably. The method used by Watmough and Matheson was the "most probable number method", according to the Standard Methods for the examination of water and waste water.

This technique was used until 1956, at which time the more precise "Membrane Filter Method" was adopted. During the changeover it was recognized that a considerable amount of the data previously collected might be useless unless some correlation could be established between the two systems.

Although an exact correlation between the two methods could not be established, there was nevertheless a good correlation between orders of magnitude, especially when averages were considered. For this reason earlier data has been included. This earlier data does affect the correlation coefficient to some extent because of rather wide variations in the most probable number method. Correlation of the data with respect to time improves considerably after 1956.

The two organisms reported in this study are *Bacillus Coliform* and *Fecal Coliform*. These bacterias are useful as indicator bacteria because of the relative ease with which they can be detected and their significances in the intestinal tract. The fecal coliform organism is a reasonably good indication of bacteria of fecal origin.

There is no doubt that the Bay waters are grossly polluted with coliform organisms. This situation has existed probably for years before the sanitary survey began. Certainly by the beginning of the survey in 1934 the concentration of coliform bacteria ranged from 100,000 to several million per 100 mls.

The actual number of these organisms in such polluted water is not as important as the trends in the orders of magnitude.

It is obvious from the detailed examination of the data that the considerable improvement in the quality of the water with respect to bacterial contamination that has taken place from 1934 to 1979 has been dramatic.

There is so much data available that the actual values of each sample and each sampling station could be confusing unless the data is grouped together in such a way as to be more meaningful. It was therefore necessary to examine the raw data in several ways in order to determine the most useful method.

It was concluded that there was not one way but several ways in which this data should be examined. Annual averages for each station could be examined for the entire period of time during which the survey took place. This would give an idea of the rate of change of pollution in different areas of the Bay.

Overall annual averages for all sampling stations were also considered useful because this could give a very good indication of the overall rate of change of pollution in the Bay.

It was also decided that monthly averages for each sampling station should be considered. This would permit the examination of same monthly data throughout the period of the survey.

In general all three of these techniques were used in order to assess the rate of change of pollution in the Bay.

Bacillus Coli

If all seven sampling stations are considered for the entire period from 1934 to 1979, the concentration of total *Bacillus Coli* has decreased. This is apparent in Fig. No. 1, which is a logarithmic plot of the annual averages for all stations from 1934 to 1979.

The data in Table No. 4 shows that the correlation coefficient for this data is 30.3%. This rather poor correlation is caused by the wide distribution of the data when an older technique was used prior to 1956. It can be seen in Fig. No. 1 that a much narrower spread of the data occurs after that date. However in spite of the relatively poor correlation there is a definite tendency for the concentration of *B. Coli* to decrease with time.

If the data prior to 1956 is excluded and only that data is examined which was obtained by the membrane filter technique, then the correlation coefficient becomes 38.4%. This data is illustrated in Fig. No. 2 and Table No. 5.

In order to determine how the concentration of coliform in the Bay has changed over the past 46 years, the data can be grouped in several different ways and then carefully examined.

The early years of the survey can be compared with the later years and any period between these extremes. Grouping of the data as follows, allows one to make certain observations which are useful.

The *B. Coliform* data was grouped into three time frames, the first one being the first 5 years of the survey from 1934-1938, the second from 1957-1961 and the third from 1975-1979. The reason for selecting the time frame of 1957-1961 was because it was immediately prior to the opening of the first stage of the Hamilton sewage treatment plant. The final period from 1975-1979 includes

Fig. No.1

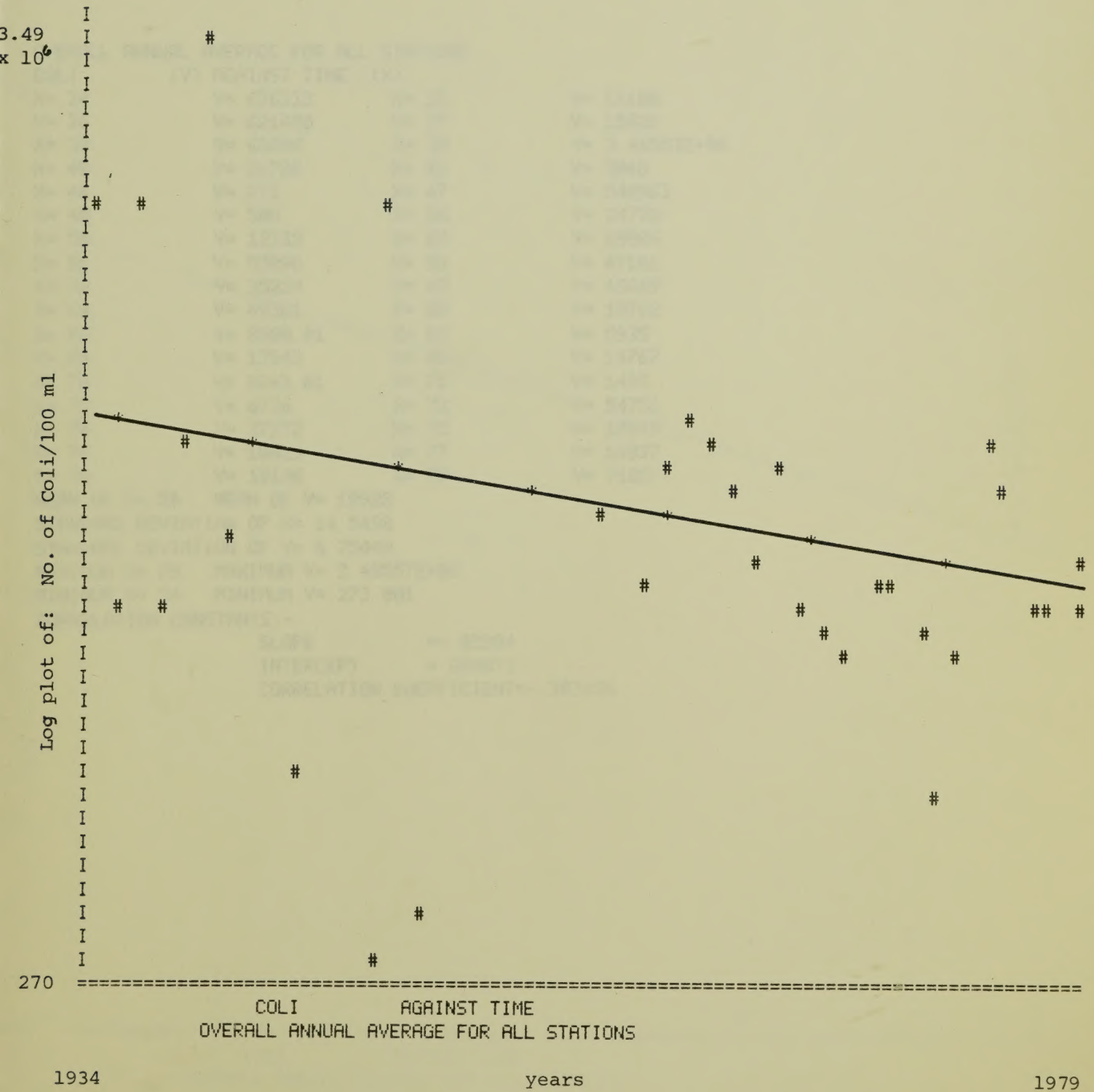


Table No.4

OVERALL ANNUAL AVERAGE FOR ALL STATIONS
COLI (Y) AGAINST TIME (X)

X= 34	Y= 636333	X= 35	Y= 11100
X= 36	Y= 621400	X= 37	Y= 11029
X= 38	Y= 60696	X= 39	Y= 3.48553E+06
X= 40	Y= 21726	X= 43	Y= 2040
X= 46	Y= 273	X= 47	Y= 540963
X= 48	Y= 500	X= 56	Y= 24789
X= 58	Y= 12339	X= 60	Y= 69006
X= 61	Y= 55890	X= 59	Y= 47181
X= 62	Y= 35224	X= 63	Y= 16669
X= 64	Y= 49361	X= 65	Y= 10762
X= 66	Y= 8500.01	X= 67	Y= 5935
X= 68	Y= 13543	X= 69	Y= 14767
X= 70	Y= 9243.01	X= 71	Y= 1495
X= 72	Y= 6726	X= 73	Y= 54751
X= 74	Y= 37972	X= 75	Y= 10049
X= 76	Y= 10813	X= 77	Y= 16837
X= 78	Y= 10196	X= 79	Y= 7182

MEAN OF X= 59 MEAN OF Y= 19928

STANDARD DEVIATION OF X= 14.5498

STANDARD DEVIATION OF Y= 6.75449

MAXIMUM X= 79 MAXIMUM Y= 3.48557E+06

MINIMUM X= 34 MINIMUM Y= 273.001

CORRELATION CONSTANTS:-

SLOPE =-.03984

INTERCEPT = 209073

CORRELATION COEFFICIENT=-.303456

Fig. No.2

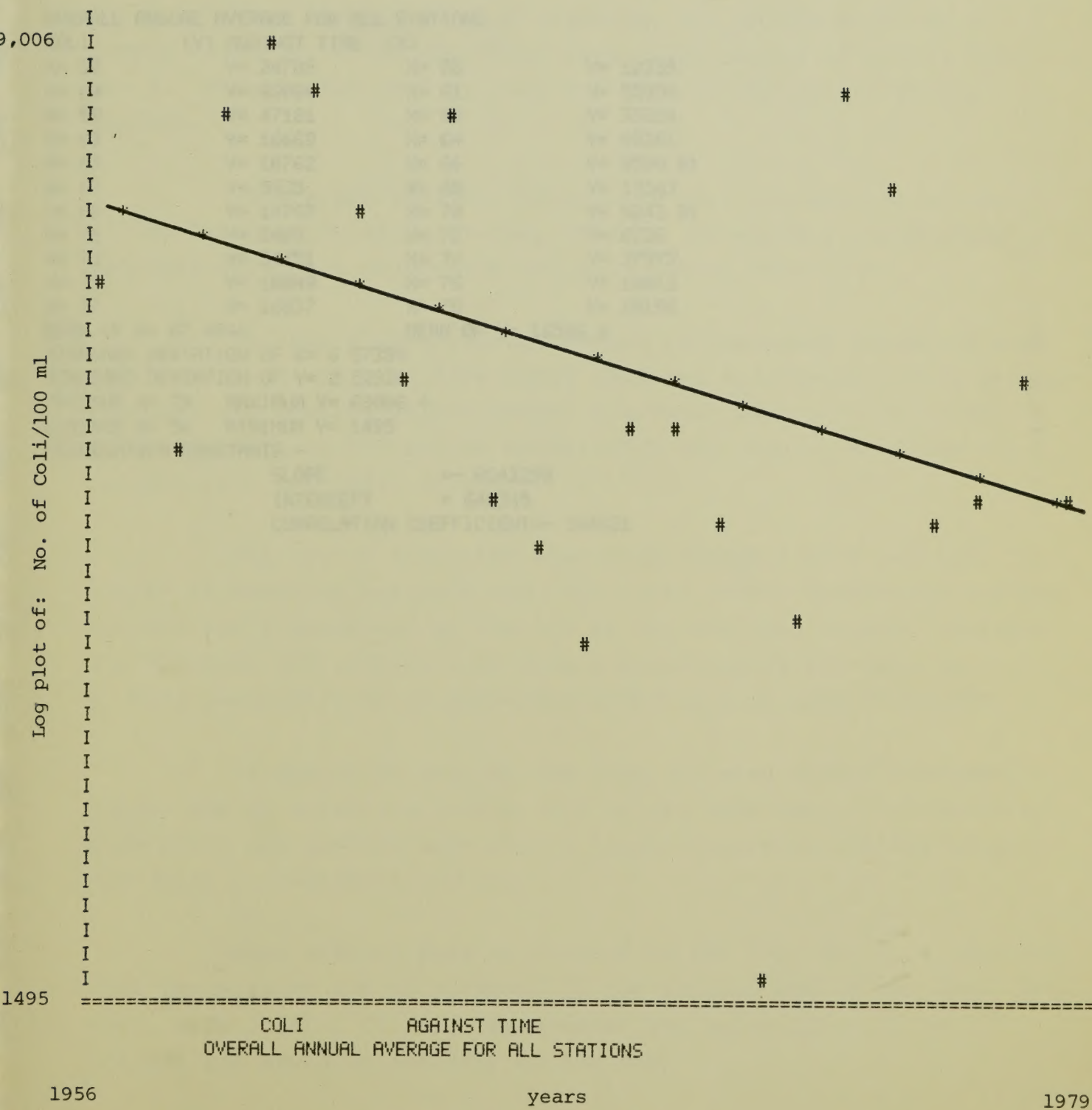


Table No.5

OVERALL ANNUAL AVERAGE FOR ALL STATIONS

COLI (Y) AGAINST TIME (X)

X= 56	Y= 24789	X= 58	Y= 12339
X= 60	Y= 69006	X= 61	Y= 55890
X= 59	Y= 47181	X= 62	Y= 35224
X= 63	Y= 16669	X= 64	Y= 49361
X= 65	Y= 10762	X= 66	Y= 8500.01
X= 67	Y= 5935	X= 68	Y= 13543
X= 69	Y= 14767	X= 70	Y= 9243.01
X= 71	Y= 1495	X= 72	Y= 6726
X= 73	Y= 54751	X= 74	Y= 37972
X= 75	Y= 10049	X= 76	Y= 10813
X= 77	Y= 16837	X= 78	Y= 10196

MEAN OF X= 67.4546

MEAN OF Y= 16526.9

STANDARD DEVIATION OF X= 6.57359

STANDARD DEVIATION OF Y= 2.52926

MAXIMUM X= 79 MAXIMUM Y= 69006.4

MINIMUM X= 56 MINIMUM Y= 1495

CORRELATION CONSTANTS:-

SLOPE = -.0543298

INTERCEPT = 645345

CORRELATION COEFFICIENT=-.384881

a period of time during which both the primary and secondary stages of the Hamilton sewage treatment plant were operational.

Fig. No. 3 illustrates the distribution of *Bacillus Coliform* throughout the Bay. Between the years 1934-1938, inclusive, there were two sources of this organism, one in the vicinity of Sample Point No. 2 and the other more major source at Sample Point No. 3. This latter location was the site of the former sewage outfall.

This graph clearly illustrates that the eastern section of the Bay was grossly polluted, whereas the norther and western sections were only moderately polluted during 1934-1938.

Because a more precise method of measuring bacterial concentration was employed from about 1957 and also because this period preceded the opening of the sewage treatment plant, the data has been processed to illustrate graphically the condition of the Bay between 1957 and 1961, inclusive.

Fig. No. 4 indicates that even though a more precise method of counting bacteria was used, very little difference existed between the eastern end of the Bay in the two time frames. However the northern and western ends show a considerable increase in *B. Coli* concentration in 1957-1961 when compared with 1934-1938.

It should be pointed out, that the same sewage treatment plant, was in existence during this entire time span. Furthermore this plant was nothing more than a coarse screening process where virtually no treatment was used.

When similar data is plotted as per Fig. No. 5, a considerable improvement can be observed in the eastern end of the Bay. However, very little, if any, improvement has taken place in the western and northern sections of the Bay.

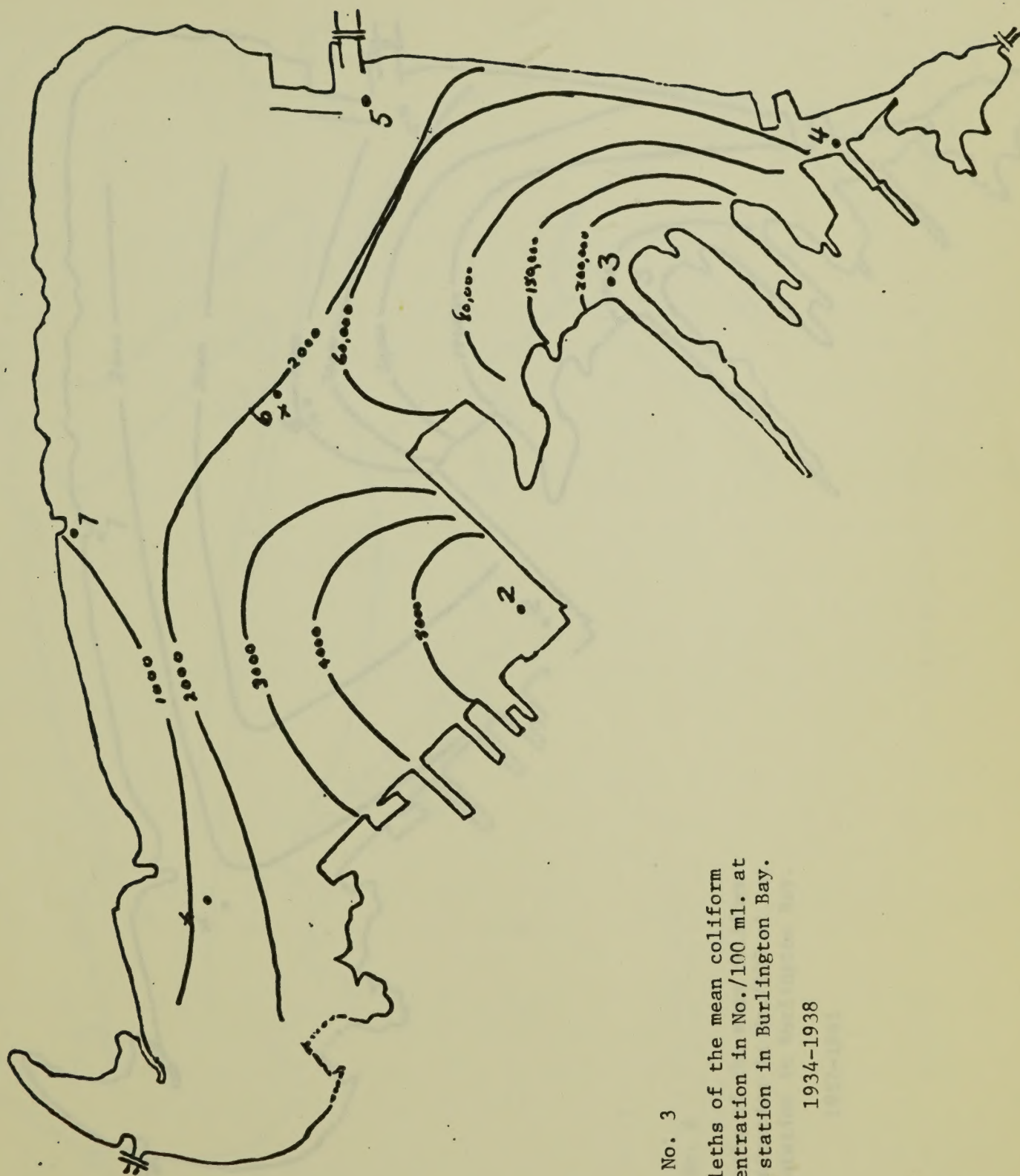


Fig. No. 3

Isopleths of the mean coliform
concentration in No./100 ml. at
each station in Burlington Bay.

1934-1938

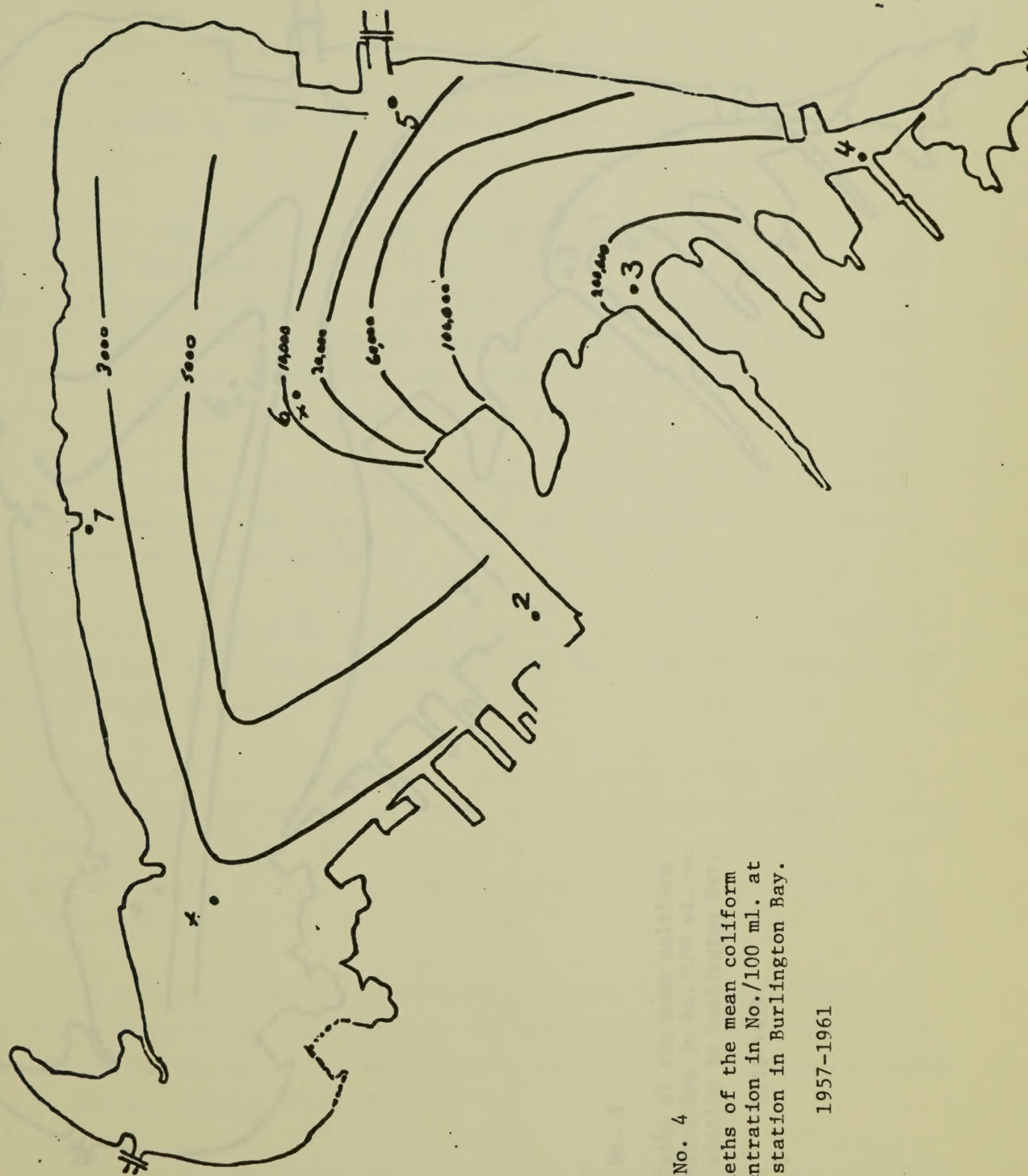


Fig. No. 4

Isopleths of the mean coliform
concentration in No./100 ml. at
each station in Burlington Bay.

1957-1961

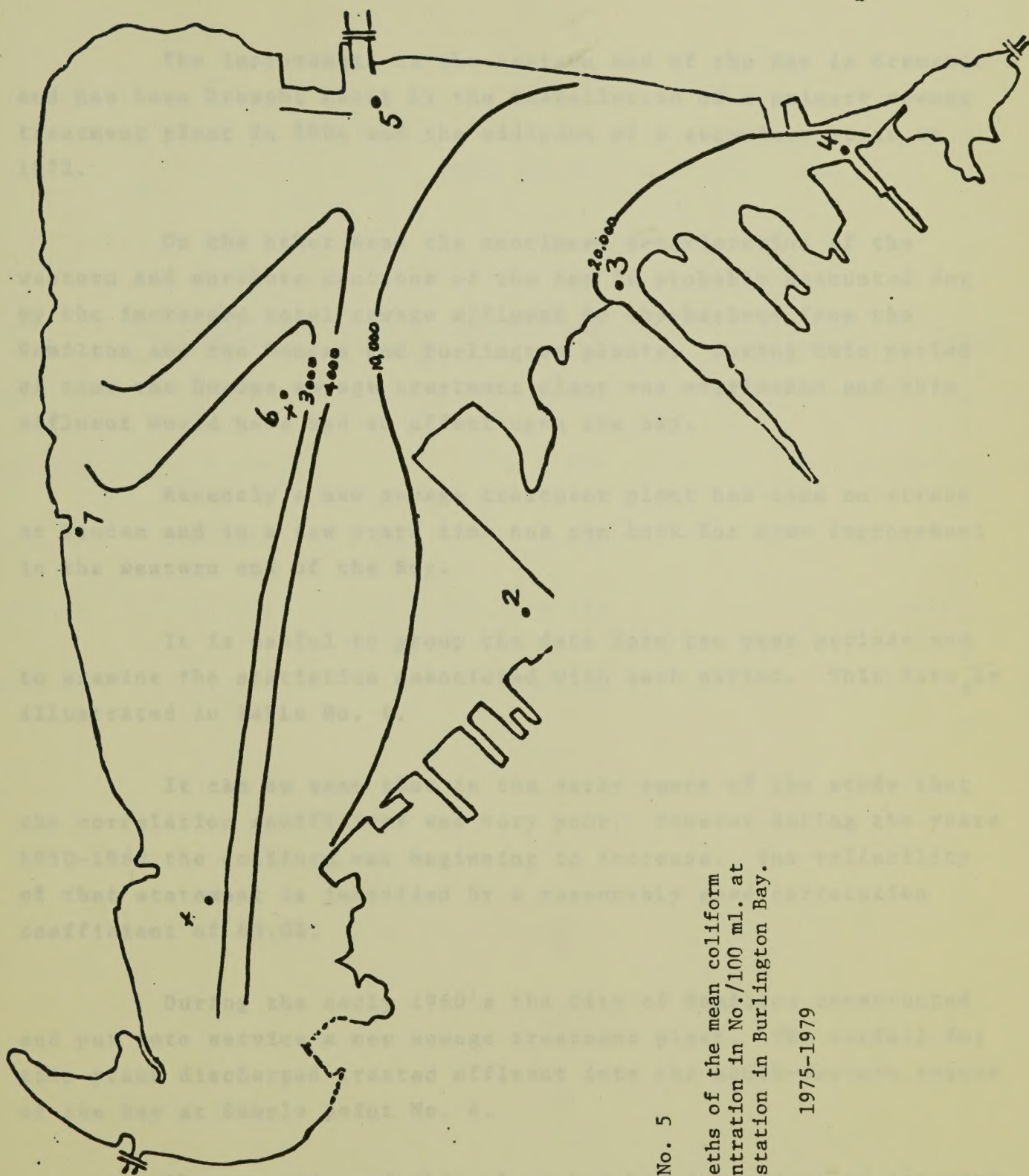


Fig. No. 5

Isopleths of the mean coliform
concentration in No./100 ml. at
each station in Burlington Bay.

1975-1979

The improvement in the eastern end of the Bay is dramatic and has been brought about by the installation of a primary sewage treatment plant in 1964 and the addition of a secondary stage in 1972.

On the other hand the continued deterioration of the western and northern sections of the Bay is probably accounted for by the increased total sewage effluent to the harbour from the Hamilton and the Dundas and Burlington plants. During this period of time the Dundas sewage treatment plant was overloaded and this effluent would have had an affect upon the Bay.

Recently a new sewage treatment plant has come on stream at Dundas and in a few years time one can look for some improvement in the western end of the Bay.

It is useful to group the data into ten year periods and to examine the statistics associated with each period. This data is illustrated in Table No. 6.

It can be seen that in the early years of the study that the correlation coefficient was very poor. However during the years 1950-1960 the coliform was beginning to increase. The reliability of that statement is justified by a reasonably good correlation coefficient of 63.0%.

During the early 1960's the City of Hamilton constructed and put into service a new sewage treatment plant. The outfall for this plant discharged treated effluent into the south-eastern corner of the Bay at Sample point No. 4.

The operation of this plant has had the effect of lowering the concentration of B. Coli during the years from 1960 to 1970. A correlation coefficient of 78.6% is strong support for the validity of a substantial reduction of the coliform concentration during this period of time - Fig. 6 and Table No. 7.

TABLE NO. 6

<u>Year</u>	<u>Mean Coliform Conc.</u> <u>No./100 ml.</u>	<u>Correlation Coeff</u>	<u>Slope</u> <u>Increase (Decrease)</u>
1930-40	112,103	- 0.032	(- 0.034)
1940-50	5,096.4	- 0.147	(- 0.140)
1950-60	31,600	0.630	0.280
1960-70	18,900	- 0.786	(- 0.201)
1970-79	11,500	0.305	0.115

Fig. No.6

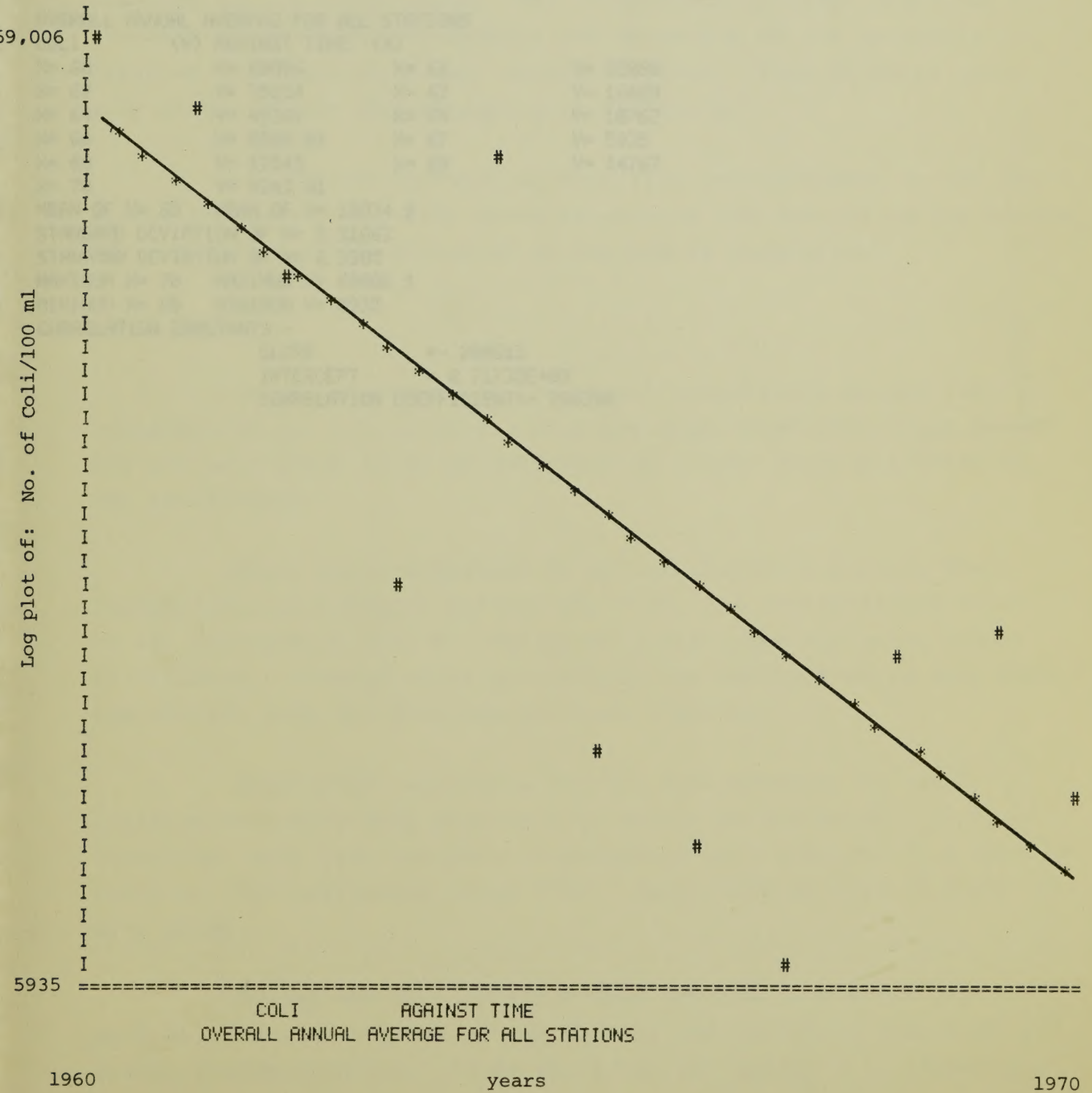


Table No.7

OVERALL ANNUAL AVERAGE FOR ALL STATIONS

COLI (Y) AGAINST TIME (X)

X= 60	Y= 69006	X= 61	Y= 55890
X= 62	Y= 35224	X= 63	Y= 16669
X= 64	Y= 49361	X= 65	Y= 10762
X= 66	Y= 8500.01	X= 67	Y= 5935
X= 68	Y= 13543	X= 69	Y= 14767
X= 70	Y= 9243.01		

MEAN OF X= 65 MEAN OF Y= 18934.9

STANDARD DEVIATION OF X= 3.31663

STANDARD DEVIATION OF Y= 2.3305

MAXIMUM X= 70 MAXIMUM Y= 69006.1

MINIMUM X= 60 MINIMUM Y= 5935

CORRELATION CONSTANTS:-

SLOPE = - .200613

INTERCEPT = 8.71735E+09

CORRELATION COEFFICIENT = - .786396

If the period between 1970 and 1980 is studied, Fig. No. 7 reveals that a slight increase in coliform took place; however, the correlation coefficient is rather poor. Close examination of the data in Table No. 8 indicates that in the early years of this particular decade the coliform concentration was relatively high when compared to the later years. The improvement in later years was probably a result of the opening and operation of the secondary stage of the Hamilton sewage treatment plant. This increase probably does not have any significance whatsoever.

Any future increase in bacterial contamination to the Bay should be minimal and will occur because of the limited volume of the Bay coming under the stress of an increasing population.

Fecal Coli

These organisms are the normal inhabitants of the lower intestine of man and animals. They are associated with fecal matter and are considered to be an indicator of recent fecal pollution in the environment.

Since these organisms do not persist very long in the inhospitable environment outside the body, the concentration found in the environment will be considerably less than the total number of coliform. However their presence in the environment is much more significant than the *Bacillus Coliform* organism.

Simplified techniques for the determination of fecal coliform have only been available in fairly recent years. It has, therefore, only been possible to determine this organism on a routine basis in this laboratory since 1968. Unfortunately only 10 years of data exist.

During the past 10 years many changes have taken place such as, the construction of the primary and secondary stages of the sewage treatment plant. It is therefore not possible to illustrate

Fig. No.7

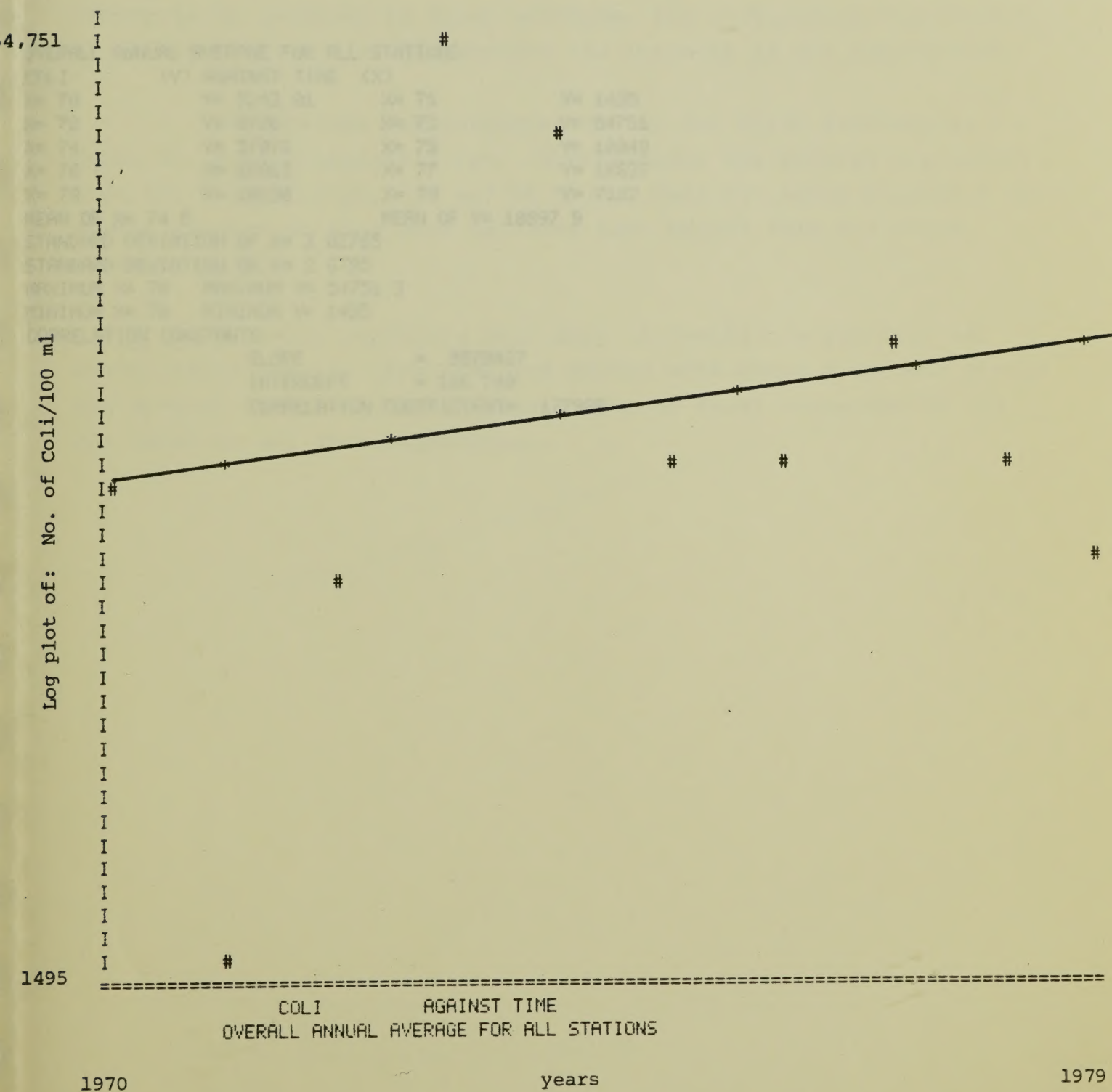


Table No.8

OVERALL ANNUAL AVERAGE FOR ALL STATIONS

COLI	(Y) AGAINST TIME	(X)	
X= 70	Y= 9243.01	X= 71	Y= 1495
X= 72	Y= 6726	X= 73	Y= 54751
X= 74	Y= 37972	X= 75	Y= 10049
X= 76	Y= 10813	X= 77	Y= 16837
X= 78	Y= 10196	X= 79	Y= 7182

MEAN OF X= 74.5 MEAN OF Y= 10997.9

STANDARD DEVIATION OF X= 3.02765

STANDARD DEVIATION OF Y= 2.6795

MAXIMUM X= 79 MAXIMUM Y= 54751.3

MINIMUM X= 70 MINIMUM Y= 1495

CORRELATION CONSTANTS:-

SLOPE = .0579427

INTERCEPT = 146.749

CORRELATION COEFFICIENT= .177988

any meaningful trends which could have taken place.

Fig. No. 8 represents a graphical illustration of the data in Table No. 9. Although the least squares plot in Fig. No. 8 indicates an increase in fecal coliform, the correlation coefficient is so poor that one could consider the increase as not significant.

The average concentration values for fecal coliform in Table No. 9 are reasonably low. Occasionally the average concentration for a particular year may be high. This may arise because a few random samples in that year may have been higher than one would normally expect.

When one considers that many of Hamilton's sanitary and storm sewers are not separated and during peak storm flow some sewage can by-pass the plant, the concentration of fecal organisms in the Bay water is not that significant.

Fig. No.8

3148

Log plot of: No. of Coli/100 ml

489

FE CAL COLI AGAINST TIME
OVERALL ANNUAL AVERAGE FOR ALL STATIONS

1968

years

1979

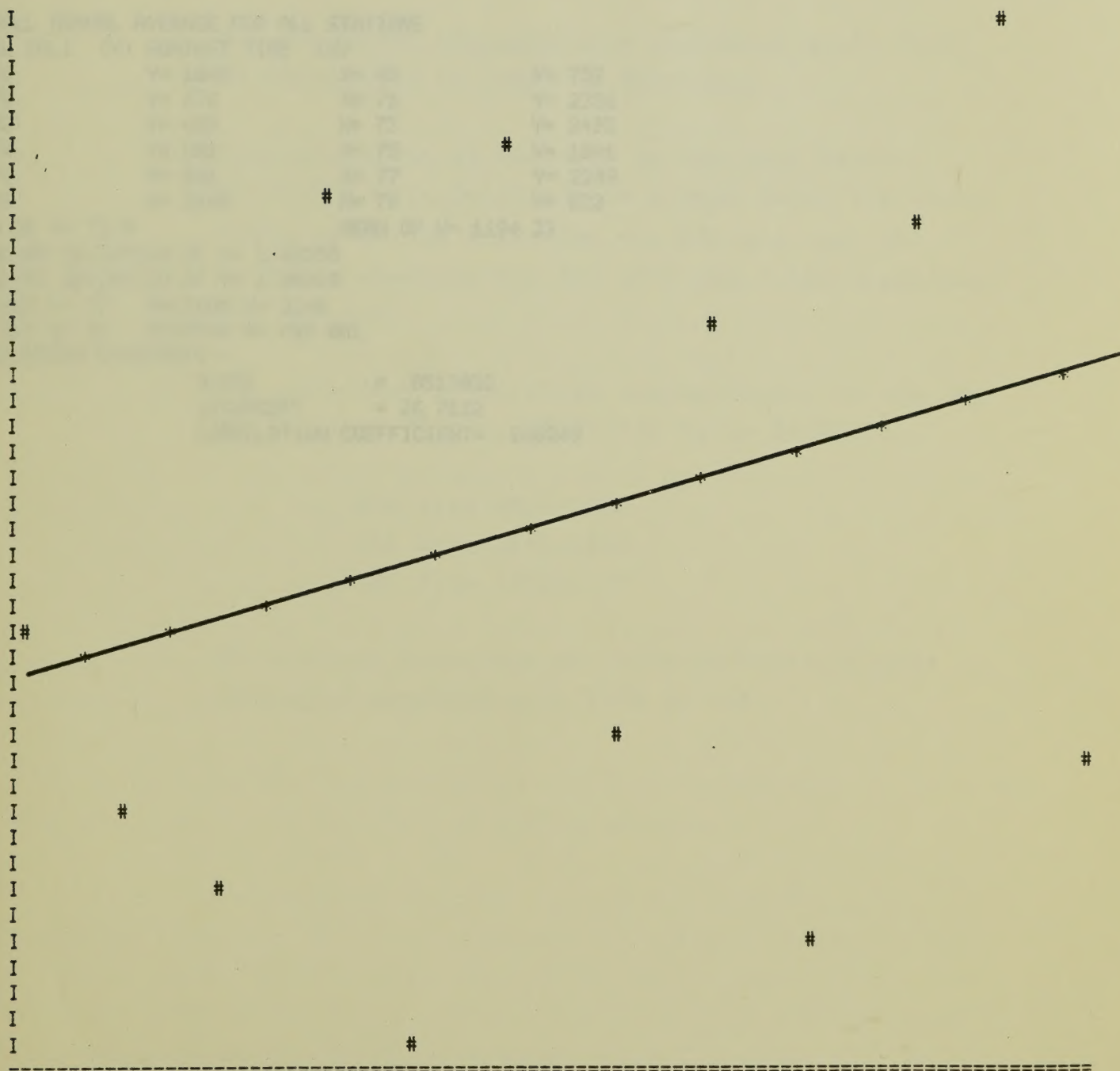


Table No.9

OVERALL ANNUAL AVERAGE FOR ALL STATIONS

FECAL COLI (Y) AGAINST TIME (X)

X= 68	Y= 1042	X= 69	Y= 752
X= 70	Y= 676	X= 71	Y= 2351
X= 72	Y= 489	X= 73	Y= 2495
X= 74	Y= 861	X= 75	Y= 1841
X= 76	Y= 601	X= 77	Y= 2249
X= 78	Y= 3148	X= 79	Y= 822

MEAN OF X= 73.5

MEAN OF Y= 1194.33

STANDARD DEVIATION OF X= 3.60555

STANDARD DEVIATION OF Y= 1.90928

MAXIMUM X= 79 MAXIMUM Y= 3148

MINIMUM X= 68 MINIMUM Y= 489.001

CORRELATION CONSTANTS:-

SLOPE = .0517032

INTERCEPT = 26.7132

CORRELATION COEFFICIENT= .288249

Bacteriological Assessment of Burlington Bay

1. Burlington Bay was severely polluted by coliform bacteria from 1934-1940.
2. The bacterial contamination increased until 1960 at which time it began to decrease.
3. Concentrations of bacteria in the past decade, 1970-1979 have decreased to a mean value for these years of 11,500 organisms per 100 mls. and the average concentration for 1979 was 7,182 organisms per 100 mls.
4. The reduction of coliform concentration in the Bay in the past decade, 1970-1979 is as follows:

90% from 1934-1940

63% from 1950-1960

39% from 1960-1970

5. The overall reduction in coliform bacteria from 1934-1940 compared with 1979 is 94%.

Chapter No. 5

CHLORIDE

The chloride ion is associated with a variety of highly soluble salts. It is not significant as a pollutant unless the concentration becomes very large. The concentration levels of chloride found in the Great Lakes system are at the moment well below levels which would be considered polluted.

However chlorides are significant because the concentration of chloride found in surface water is usually proportional to the concentration of other ions or compounds which are more significant as pollutants.

It is therefore interesting to measure the chloride ion concentration over a period of time in order to indicate the degree of contamination which may have occurred.

Because of the highly soluble nature of chloride salts, most of the so-called natural chloride would have been washed free off the land and transported to the ocean.

Any recent increase in chloride ion would then be a direct consequence of human activity in the environment.

At the beginning of this survey, between the years 1934-1938, the mean chloride concentration of Burlington Bay was 21 p.p.m. When this is compared with the mean concentration for the years 1974-1979 which is 65 p.p.m., it becomes apparent that a substantial increase of 210% has taken place.

This gives one a good idea of the amount of contamination which has taken place over the years.

There are three significant sources of chloride contamination to the Bay, these are - salting of the roads during the winter months with subsequent run off to the Bay, the chloride ion in the sewage effluent, and also the chloride in industrial waste water.

If the chloride ion concentration was not increasing one could assume that the pollution of the Bay waters had reached a steady state. Under such conditions the dilution of the contaminants or the throughput of the contaminants was under control. However it cannot be said that the Bay has reached a steady state.

Because chloride ion is readily soluble in water and because it is not altered in any biological activity, it can be an excellent measure of the extent to which the Bay water has been contaminated. Furthermore the concentration of this ion reflects the extent to which human activity takes place in the watershed.

Since 1934 to 1979 there has been a three-fold increase in the chloride ion concentration. If the increase in the chloride ion is compared with the increase in population, the correlation coefficient is 94.1%. This indicates that there is a direct relationship between the increase in concentration of this ion and the increase in population. Apparently as the population doubles there is a three-fold increase in the chloride ion concentration.

While chloride is not harmful, and at the concentration found in the Bay water could hardly be termed a pollutant, it is nevertheless an excellent yard stick for measuring the degree of contamination which has occurred.

However this does not mean that all other pollution parameters have increased by a factor of three. Some, such as bacteria, will have increased to a greater extent, whereas, the compounds assimilated by the biological species may be found at

concentrations much less than one might expect.

Fig. No. 9 and Table No. 10 indicate the regularity with which the chloride ion has increased from 1934-1979.



Fig. No.9

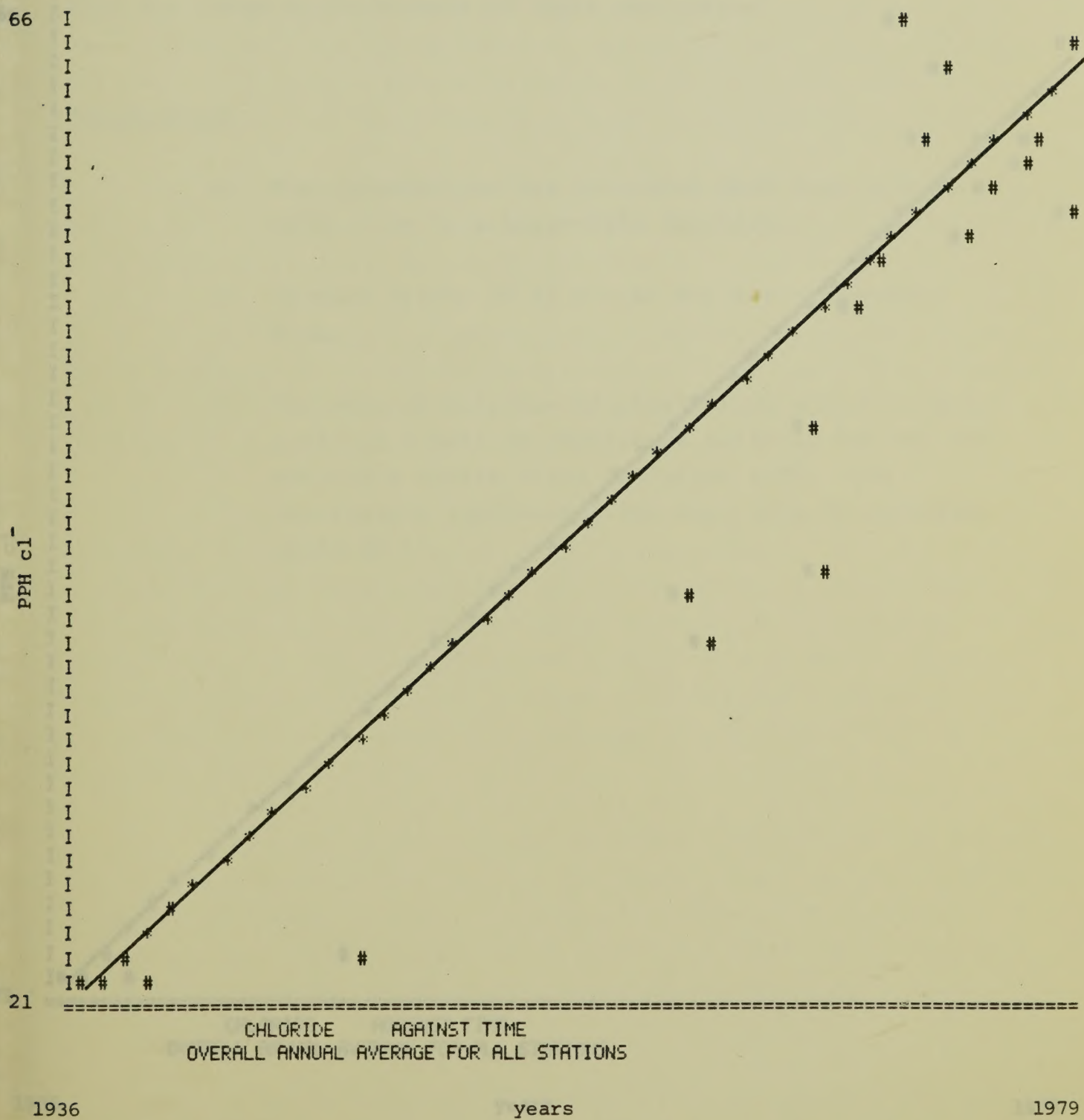
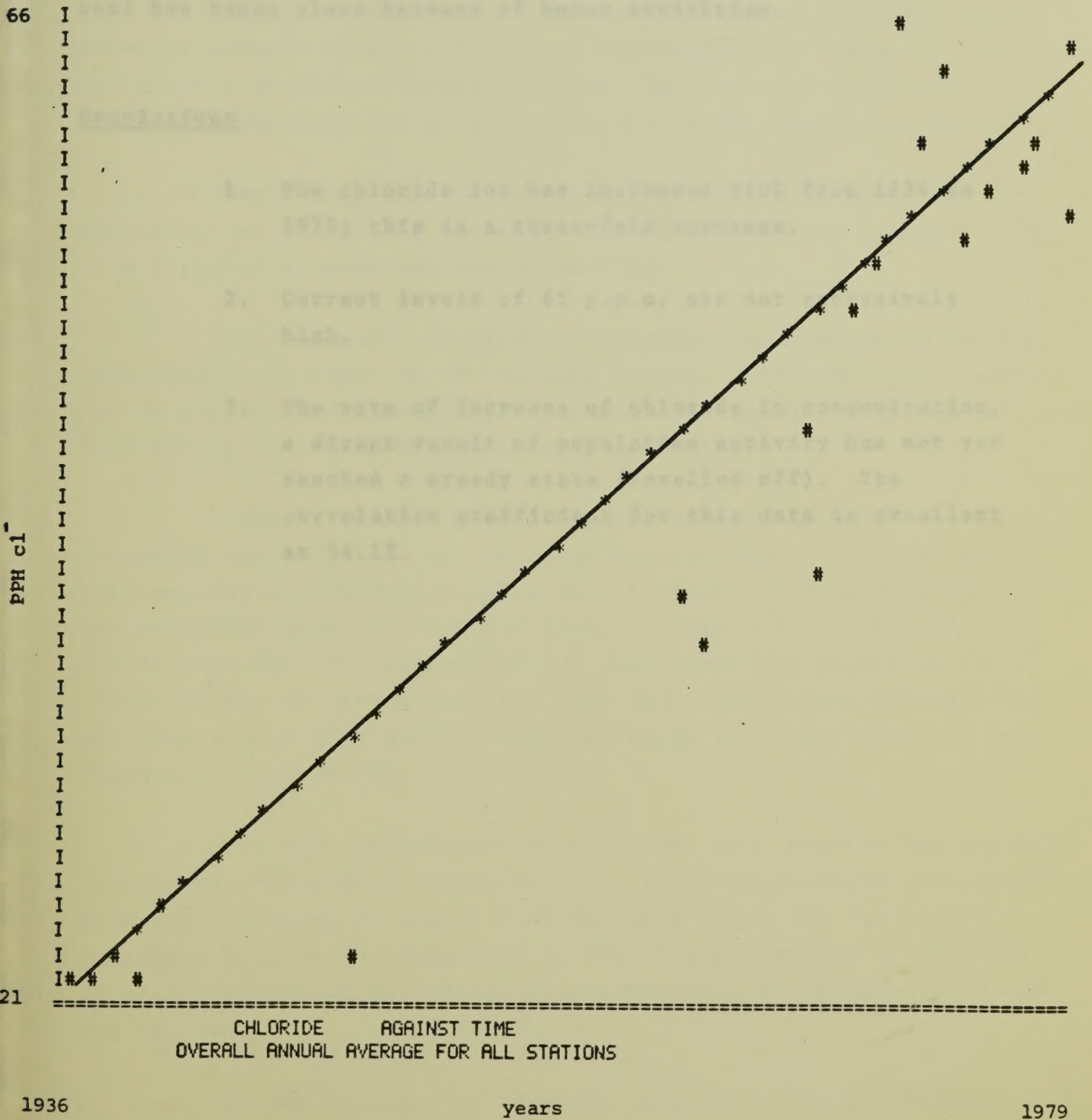


Fig. No.9



Chloride Ion Assessment

Chloride ion is an innoxious chemical species, it does however indicate in a relative manner the amount of contamination that has taken place because of human activities.

Conclusions

1. The chloride ion has increased 210% from 1934 to 1979; this is a three-fold increase.
2. Current levels of 65 p.p.m. are not excessively high.
3. The rate of increase of chloride in concentration, a direct result of population activity has not yet reached a steady state (levelled off). The correlation coefficient for this data is excellent at 94.1%.

Chapter No. 6

NITRATE-NITROGEN

There are a number of different chemical compounds which could be present in the influent to Burlington Bay. Most of these are present in either sewage or industrial waste; the two most important compounds are those containing either ammonia or nitrate.

Since compounds of nitrogen are subject to oxidation and biological activity, the concentration of the various compounds are in a state of fluctuating concentrations.

The compounds of nitrate represent the highest oxidation state generally found in our surface waters. Although this compound can be utilized by biological organisms, its concentration in surface waters is not subject to wide fluctuation.

Nitrate therefore is a reasonable good indicator of the pollution load which a body of water has received. Fig. No. 10 representing the data from Table No. 11 shows the variation in concentration about the line of least squares. A correlation coefficient for this data of 77.2 % indicates the degree of reliability one can place upon the fact that the nitrate-nitrogen is increasing with time since the pollution of the waters has not yet reached a steady state.

The data for nitrate-nitrogen for each station was grouped into years indicated in Table No. 12. Each concentration of nitrate-nitrogen expressed in p.p.m. N is the mean value for that year. Comparing mean values from year to year has a tendency to even out fluctuations caused by biological assimilation at various times during the year.

It may be observed from the data that Sampling Station No. 7 has been consistently higher than most other locations in the

Fig. No. 10

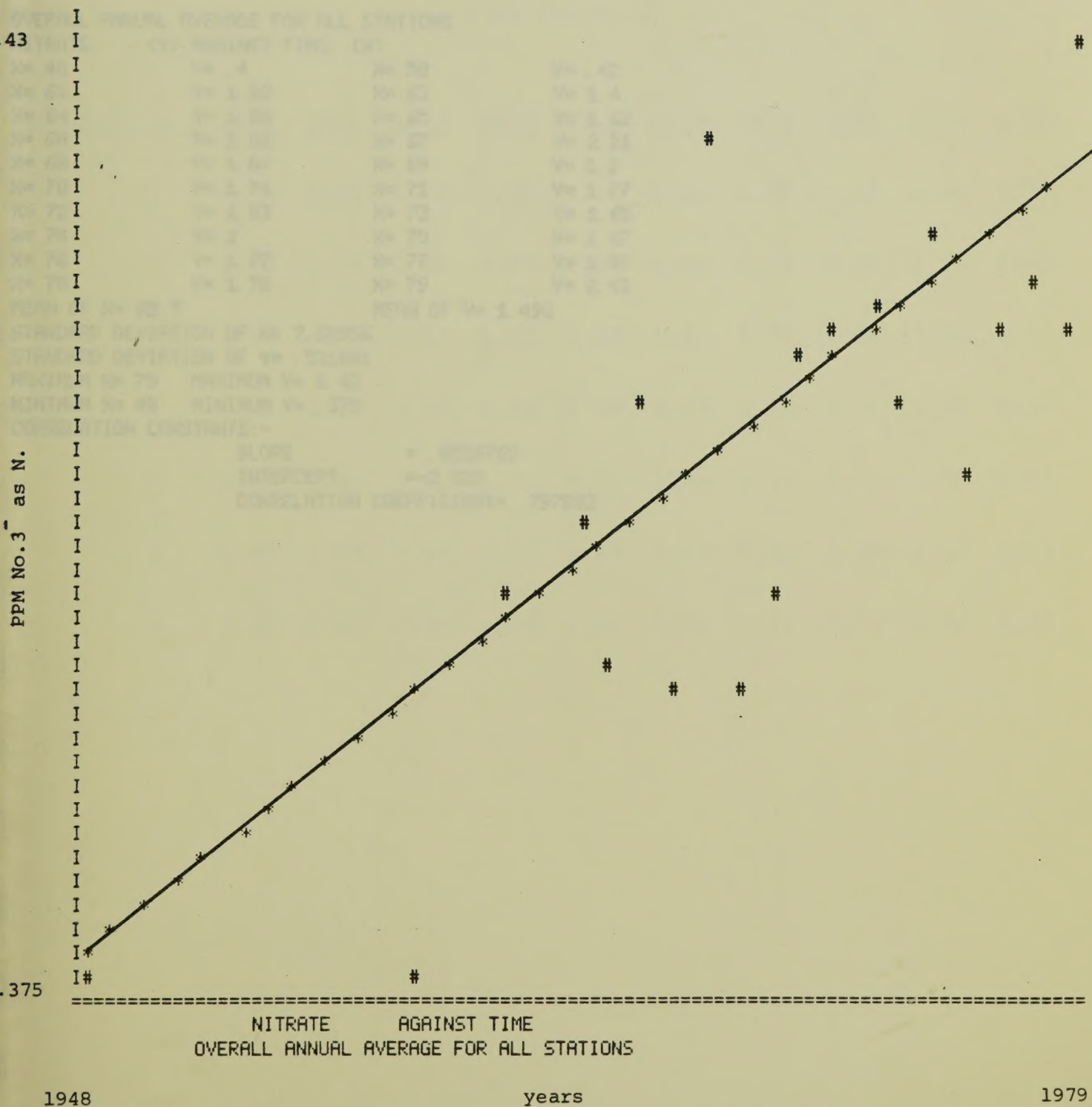


Table No. 11

OVERALL ANNUAL AVERAGE FOR ALL STATIONS

NITRATE (Y) AGAINST TIME (X)

X= 48	Y= .4	X= 58	Y= .42
X= 61	Y= 1.22	X= 63	Y= 1.4
X= 64	Y= 1.08	X= 65	Y= 1.62
X= 66	Y= 1.02	X= 67	Y= 2.21
X= 68	Y= 1.04	X= 69	Y= 1.2
X= 70	Y= 1.74	X= 71	Y= 1.77
X= 72	Y= 1.83	X= 73	Y= 1.65
X= 74	Y= 2	X= 75	Y= 1.47
X= 76	Y= 1.77	X= 77	Y= 1.87
X= 78	Y= 1.78	X= 79	Y= 2.43

MEAN OF X= 68.7

MEAN OF Y= 1.496

STANDARD DEVIATION OF X= 7.60956

STANDARD DEVIATION OF Y= .531001

MAXIMUM X= 79 MAXIMUM Y= 2.43

MINIMUM X= 48 MINIMUM Y= .375

CORRELATION CONSTANTS:-

SLOPE = .0556769

INTERCEPT = -2.329

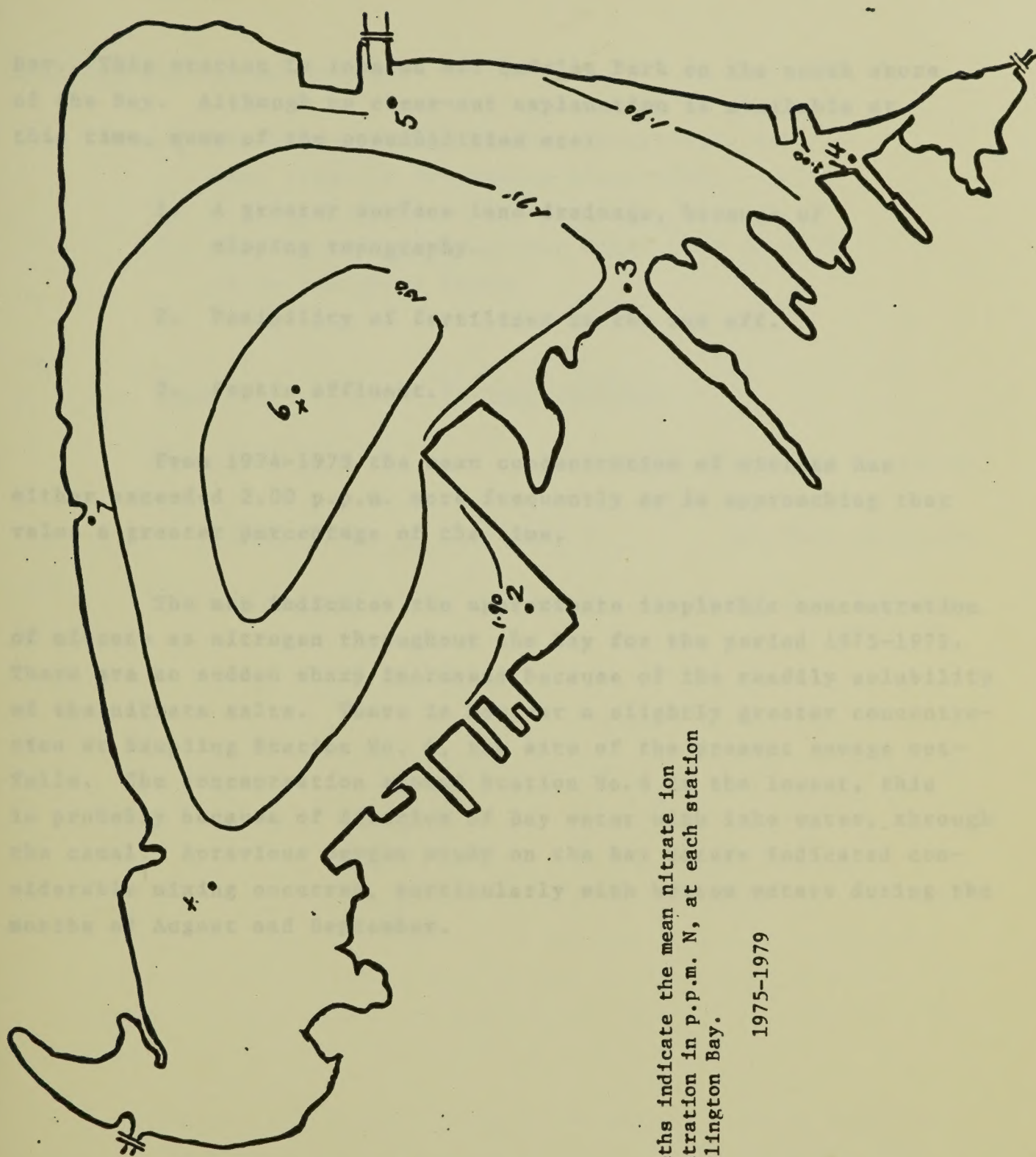
CORRELATION COEFFICIENT= .797883

TABLE NO. 12

MEAN CONCENTRATION OF NO_3^- AS N

(in p.p.m.)

<u>Station No.</u>	<u>1970</u>	<u>1971</u>	<u>1972</u>	<u>1973</u>	<u>1974</u>	<u>1975</u>	<u>1976</u>	<u>1977</u>	<u>1978</u>	<u>1979</u>
1	1.79	1.81	1.91	1.71	2.02	1.44	1.74	1.62	1.61	2.56
2	1.88	1.74	1.94	1.77	2.03	1.44	1.71	2.93	1.58	2.27
3	1.53	1.97	1.68	1.60	1.88	1.37	1.77	1.66	1.84	2.21
4	1.37	1.20	1.61	1.19	1.87	1.49	1.43	1.76	2.48	3.05
5	1.69	1.87	1.85	1.75	2.05	1.48	2.28	1.71	1.85	2.39
6	1.90	1.83	1.95	1.75	2.02	1.54	1.69	1.68	1.55	2.33
7	2.00	2.00	1.86	1.76	2.10	1.52	1.76	1.75	1.58	2.33



Isopleths indicate the mean nitrate ion concentration in p.p.m. N, at each station in Burlington Bay.

1975-1979

Bay. This station is located off LaSalle Park on the north shore of the Bay. Although no clear-cut explanation is available at this time, some of the possibilities are:

1. A greater surface land drainage, because of sloping topography.
2. Possibility of fertilizer in the run off.
3. Septic effluent.

From 1974-1979 the mean concentration of nitrate has either exceeded 2.00 p.p.m. more frequently or is approaching that value a greater percentage of the time.

The map indicates the approximate isoplethic concentration of nitrate as nitrogen throughout the Bay for the period 1975-1979. There are no sudden sharp increases because of the readily solubility of the nitrate salts. There is however a slightly greater concentration at Sampling Station No. 4, the site of the present sewage outfalls. The concentration around Station No. 6 is the lowest, this is probably because of dilution of Bay water with lake water, through the canal. A previous oxygen study on the Bay waters indicated considerable mixing occurred, particularly with bottom waters during the months of August and September.

Nitrate-Nitrogen Assessment

1. The concentration of nitrate-nitrogen has been steadily increasing since 1948.
2. The nitrate has increased since 1948 to 1979 as is indicated below:

<u>Year</u>	<u>Percent Increase</u>	
From 1948-1979	84 %	Six-fold increase.
1961-1979	50 %	Two-fold increase.
1970-1979	28 %	1.4-fold increase.

High concentrations of phosphorus have never been a serious problem in Burlington Bay. Although the same normally high concentrations of phosphorus compounds were entering the Bay as in many other lakes and streams in the province, the Bay has not exhibited excessive algal growth. One can speculate upon the many reasons for this, but all of the analyses ever done at Burlington Bay have never shown abnormally high concentrations of phosphorus in solution. There is considerable iron in the bottom of the Bay waters, particularly from the steel mills. Since iron reacts with phosphorus compounds to form the very insoluble pyrophosphates, most of phosphorus then was effectively removed from solution as a precipitate.

Because phosphorus was never found to be a serious contaminant of Burlington Bay, measurements were not routinely made until the early 80's.

A government order restricting the use of phosphate compounds was eliminating their use in household detergents (which

Chapter No. 7

PHOSPHORUS

Phosphorus is an element which has received a great deal of notoriety since we have been made more aware of the environment in which we live. This element, even at the parts per million level found in the lakes and streams is not toxic.

The problem which phosphorus causes in the environment is excessive biological growth. It is a nutrient element and relatively small amounts stimulate rapid growth among aquatic biota.

Because many lakes and streams in the world were becoming "overgrown" with algae and aquatic weeds, some governments and their agencies imposed sever restrictions of the use of phosphorus compounds.

High concentrations of phosphorus have never been a serious problem in Burlington Bay. Although the same normally high concentrations of phosphorus compounds were entering the Bay as in many other lakes and streams in the province, the Bay has not exhibited excessive algae growth. One can speculate upon the many reasons for this, but all of the analyses ever done on Burlington Bay have never shown abnormally high concentrations of phosphorus in solution. There is considerable iron in the influent to the Bay waters, particularly from the steel mills. Since iron reacts with phosphorus compounds to form the very insoluble pyrophosphates, most of phosphorus then was effectively removed from solution as a precipitate.

Because phosphorus was never deemed to be a serious contaminant of Burlington Bay, measurements were not routinely made until the early '60's.

A government order restricting the use of phosphate compounds and eleminating their use in household detergents further

reduced phosphate levels in the Bay to very low levels.

This can be seen in Table No. 13 and it is dramatically illustrated in Fig. No. 12. It is quite evident that after the restriction upon the use of phosphate a sudden decline in the mean phosphorus concentration began to take effect in 1972

The restriction on the use of phosphate compounds took place in the early 1970's. Further evidence of the impact of this restriction is indicated in Table No. 14. This table has grouped the phosphate data into three specific time frames. Although there is an anomolous result for Station No. 1, in general, phosphate has been reduced substantially at all stations.

TOTAL PPM AGAINST TIME
SMALL SCALE CHANGE FOR ALL STATIONS

1961

1972

1973

Fig. No.12

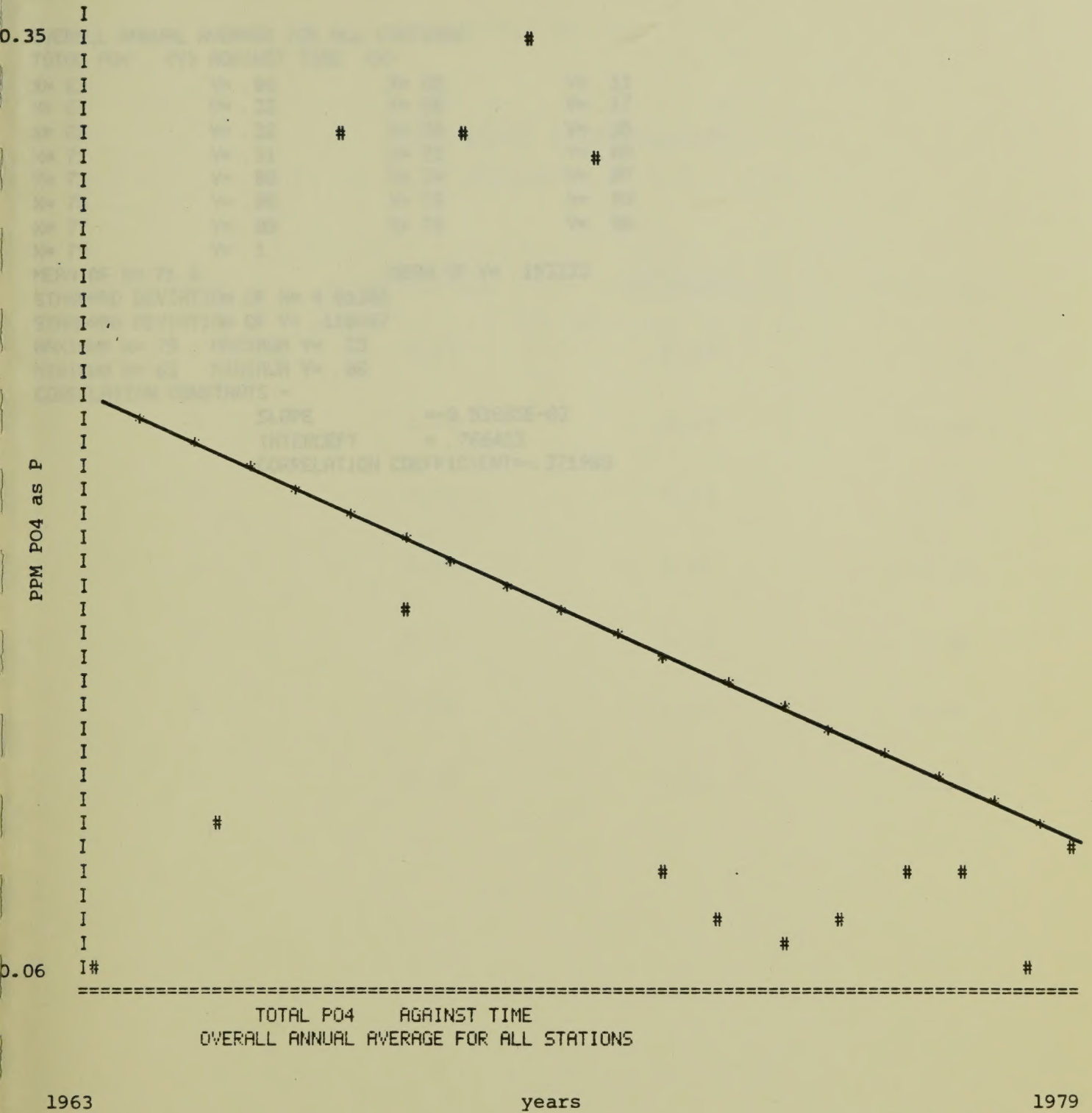


Table No.13

OVERALL ANNUAL AVERAGE FOR ALL STATIONS

TOTAL PO4 (Y) AGAINST TIME (X)

X= 63	Y= .06	X= 65	Y= .11
X= 67	Y= .32	X= 68	Y= .17
X= 69	Y= .32	X= 70	Y= .35
X= 71	Y= .31	X= 72	Y= .09
X= 73	Y= .08	X= 74	Y= .07
X= 75	Y= .08	X= 76	Y= .09
X= 77	Y= .09	X= 78	Y= .06
X= 79	Y= .1		

MEAN OF X= 71.8

MEAN OF Y= .153333

STANDARD DEVIATION OF X= 4.81366

STANDARD DEVIATION OF Y= .110497

MAXIMUM X= 79 MAXIMUM Y= .35

MINIMUM X= 63 MINIMUM Y= .06

CORRELATION CONSTANTS:-

SLOPE = -8.53885E-03

INTERCEPT = .766423

CORRELATION COEFFICIENT= -.371985

TABLE NO. 14

PHOSPHORUS CONCENTRATION

(in p.p.m. as P)

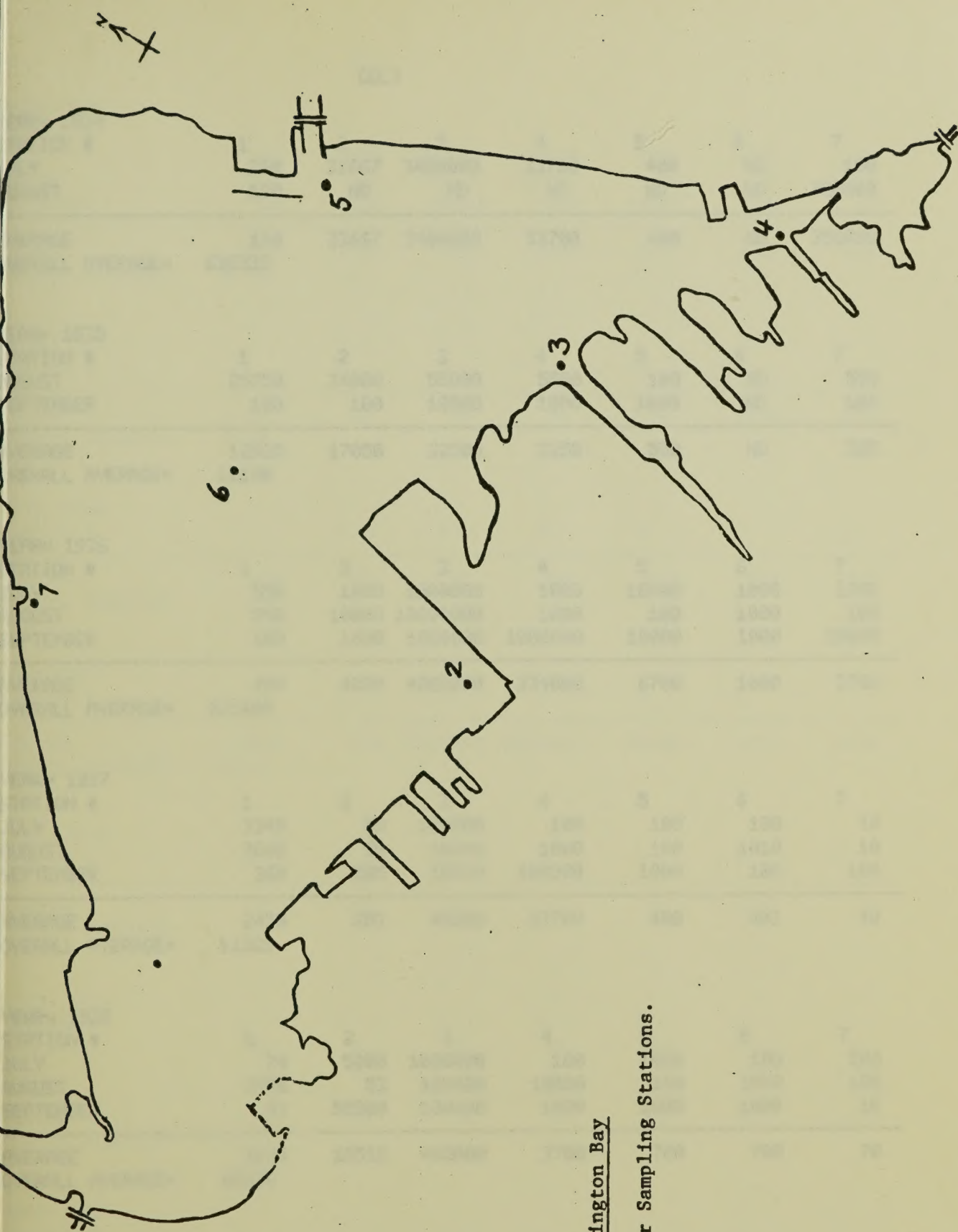
<u>Station No.</u>	<u>1963-1969</u>	<u>1970-1974</u>	<u>1975-1979</u>
1	0.21	0.08	0.18
2	0.13	0.09	0.06
3	0.20	0.11	0.07
4	0.29	0.68	0.20
5	0.16	0.12	0.09
6	0.20	0.10	0.05
7	0.20	0.09	0.05

Phosphate - Assessment

1. Phosphate concentrations have decreased considerably since the restrictions on phosphorus compounds came into effect.
2. A dramatic reduction in phosphates occurred in 1972 when the concentrations reduced from 0.35 p.p.m. the previous year to 0.09 p.p.m.

APPENDIX

Amherst Bay
near sampling stations.



Burlington Bay

Water Sampling Stations.

COLI

YEAR= 1934

STATION #	1	2	3	4	5	6	7
JULY	260	33667	3400000	33700	400	ND	100
AUGUST	100	ND	ND	ND	ND	ND	700000

AVERAGE	180	33667	3400000	33700	400	ND	350050
OVERALL AVERAGE=	636333						

YEAR= 1935

STATION #	1	2	3	4	5	6	7
AUGUST	25750	34000	55000	5500	100	ND	550
SEPTEMBER	100	100	10000	1000	1000	ND	100

AVERAGE	12925	17050	32500	3250	550	ND	325
OVERALL AVERAGE=	11100						

YEAR= 1936

STATION #	1	2	3	4	5	6	7
JULY	550	1000	1000000	1000	10000	1000	1000
AUGUST	550	10000	10000000	1000	100	1000	100
SEPTEMBER	100	1000	1000000	1000000	10000	1000	10000

AVERAGE	400	4000	4000000	334000	6700	1000	3700
OVERALL AVERAGE=	621400						

YEAR= 1937

STATION #	1	2	3	4	5	6	7
JULY	3340	55	100000	100	100	100	10
AUGUST	3668	50	10000	1000	100	1010	10
SEPTEMBER	368	505	10000	100000	1000	100	100

AVERAGE	2459	203	40000	33700	400	403	40
OVERALL AVERAGE=	11029						

YEAR= 1938

STATION #	1	2	3	4	5	6	7
JULY	70	5000	1000000	100	1000	100	100
AUGUST	3400	53	100000	10000	100	1000	100
SEPTEMBER	83	50500	100000	1000	1000	1000	10

AVERAGE	1184	18518	400000	3700	700	700	70
OVERALL AVERAGE=	60696						

YEAR= 1939

STATION #	1	2	3	4	5	6	7
JULY	3700	55	30000000	1000	1000	100000	0
AUGUST	3700	5005	1000000	1000	100	1000	1000
SEPTEMBER	100	100000	100000	ND	ND	ND	100

AVERAGE	2500	35020	10366700	1000	550	50500	367
OVERALL AVERAGE=	3485530						

COLI

YEAR= 1940

STATION #	1	2	3	4	5	6	7
JULY	600	5000	100000	100000	1000	100	100
AUGUST	3668	503	100000	100000	0	0	10000
SEPTEMBER	68	5005	10000	10000	10000	100	100

AVERAGE	1445	3503	70000	70000	3667	67	3400
OVERALL AVERAGE=	21726						

YEAR= 1943

STATION #	1	2	3	4	5	6	7
AVERAGE	650	ND	ND	ND	ND	5300	170
OVERALL AVERAGE=	2040						

YEAR= 1946

STATION #	1	2	3	4	5	6	7
AVERAGE	410	ND	ND	ND	ND	310	100
OVERALL AVERAGE=	273						

YEAR= 1947

STATION #	1	2	3	4	5	6	7
AVERAGE	1880	850	2030000	1700000	50300	1890	1820
OVERALL AVERAGE=	540963						

YEAR= 1948

STATION #	1	2	3	4	5	6	7
AVERAGE	ND	ND	ND	ND	ND	1000	0
OVERALL AVERAGE=	500						

YEAR= 1956

STATION #	1	2	3	4	5	6	7
APRIL	ND	ND	ND	ND	1920	2983	ND
MAY	ND	ND	43	ND	23	7300	9300
AVERAGE	ND	ND	43	ND	972	5142	93000
OVERALL AVERAGE=	24789						

YEAR= 1958

STATION #	1	2	3	4	5	6	7
MAY	5000	ND	ND	ND	1700	13600	28500
JUNE	5000	ND	ND	ND	1856	1800	338
JULY	3975	ND	ND	ND	36733	43633	22575
AUGUST	1250	ND	ND	ND	1075	35553	710
SEPTEMBER	8373	ND	ND	ND	22525	23525	1900
OCTOBER	300	ND	ND	ND	18000	17000	1050
AVERAGE	3997	ND	ND	ND	13648	22532	9179
OVERALL AVERAGE=	12339						

COLI

YEAR= 1959

STATION #	1	2	3	4	5	6	7
APRIL	1050	3750	5500	52500	300	850	0
MAY	1300	2400	71250	28000	1675	235	205
JUNE	590	1490	97200	4500	620	872	346
JULY	675	2550	55000	78333	775	538	588
AUGUST	775	14075	521000	100333	4100	1750	1750
SEPTEMBER	1600	50000	791999	274000	62920	7960	1850
OCTOBER	2025	4100	85000	317000	2475	10700	8525
NOVEMBER	2750	9175	55500	146500	975	623	1218
DECEMBER	1367	1467	4333	40000	133	1233	877

AVERAGE	1348	12112	187420	116796	8133	2751	1709
OVERALL AVERAGE=	47181						

YEAR= 1960

STATION #	1	2	3	4	5	6	7
APRIL	3000	600	80000	18000	5600	90	70
MAY	720	5540	16600	52300	1920	3850	1378
JUNE	313	1850	545175	92500	11500	3663	900
JULY	2375	2650	512500	234250	24650	1525	920
AUGUST	2460	7800	362000	115800	8500	28700	2940
SEPTEMBER	1100	5850	597500	73250	1450	13625	1475
OCTOBER	350	4500	222000	301750	2350	2475	975

AVERAGE	1474	4113	333682	126836	7996	7704	1237
OVERALL AVERAGE=	69006						

YEAR= 1961

STATION #	1	2	3	4	5	6	7
APRIL	1067	1600	22667	2000	1067	2783	420
MAY	834	2080	19000	7600	2140	2388	652
JUNE	975	1975	327500	64250	22275	1975	1275
JULY	4940	8480	314000	199400	8980	4740	980
AUGUST	11525	14900	380000	293250	12025	134925	26400
SEPTEMBER	50035	12000	999999	80000	20000	55000	2300
OCTOBER	5225	21250	63250	54250	9800	7975	1450
NOVEMBER	1700	2600	17500	65000	1300	3100	400
DECEMBER	1800	2167	13333	37000	1267	567	1567

AVERAGE	8678	745	239694	89194	18562	23717	3938
OVERALL AVERAGE=	55890						

YEAR= 1962

STATION #	1	2	3	4	5	6	7
APRIL	167	100	27667	8667	3150	367	807
MAY	560	1260	65400	84200	7120	33940	2140
JUNE	2878	3225	511250	73250	8325	5225	1567
JULY	8088	6460	76400	10250	5860	2360	4934
AUGUST	76470	28463	564000	26857	1900	4583	5410
SEPTEMBER	490	1433	6667	13017	535	790	1076
OCTOBER	380	425	31000	4000	575	1360	905

AVERAGE	12719	5909	183198	31463	3924	6946	2406
OVERALL AVERAGE=	35224						

COLI

YEAR= 1963

STATION #	1	2	3	4	5	6	7
MAY	1456	1570	14860	43520	700	1028	306
JUNE	1043	467	9150	9100	550	350	340
JULY	506	3540	31300	6860	2500	410	314
AUGUST	2033	3200	267567	7767	1900	2317	390
SEPTEMBER	2400	15000	23267	56850	2000	1015	610
OCTOBER	900	700	45000	10000	6000	800	500

AVERAGE	1389	4080	65191	22350	2275	987	410
OVERALL AVERAGE=	16669						

YEAR= 1964

STATION #	1	2	3	4	5	6	7
APRIL	2393	1700	1333	79667	4137	223	317
MAY	3548	29325	12000	18667	3925	680	865
JUNE	9580	24440	52920	63180	23020	892	1640
JULY	11100	3438	50000	60000	3588	1913	713
AUGUST	3804	12586	34429	125143	8029	1614	2240
SEPTEMBER	36	5186	11471	83571	3183	1150	1917
OCTOBER	1217	11500	24333	843333	15000	1538	967
NOVEMBER	27	16000	60000	950000	66000	6300	2250

AVERAGE	4734	13022	30811	277945	15860	1789	1364
OVERALL AVERAGE=	49361						

YEAR= 1965

STATION #	1	2	3	4	5	6	7
MAY	30	3000	5500	75000	0	5	75
JUNE	353	1202	3333	7400	1000	375	122
JULY	505	1400	41667	50000	1275	500	ND
AUGUST	613	2000	35000	3000	375	600	475
SEPTEMBER	2000	10000	30250	5500	1000	5	500
OCTOBER	888	6250	3325	84333	2233	2813	1050

AVERAGE	732	3975	19846	48638	981	716	444
OVERALL AVERAGE=	10762						

YEAR= 1966

STATION #	1	2	3	4	5	6	7
JUNE	1030	7453	3698	12700	1283	675	928
JULY	2225	9000	2025	15725	1383	3003	2100
AUGUST	2567	18283	30267	30300	9210	12733	2543
SEPTEMBER	10000	15250	11500	21500	2700	7000	4400

AVERAGE	3134	12497	11823	20056	3644	5853	2493
OVERALL AVERAGE=	8500						

COLI

YEAR= 1967

STATION #	1	2	3	4	5	6	7
APRIL	680	2000	34000	58000	5400	9400	3000
MAY	490	4650	8425	17150	155	1400	390
JUNE	1063	3656	17617	1017	600	1428	795
JULY	433	3400	3767	2667	2300	3700	463
AUGUST	2363	7900	3250	4463	321	528	681
SEPTEMBER	2550	5950	2750	7500	735	200	2843
OCTOBER	2050	1800	48350	5500	2140	600	280
AVERAGE	1376	4193	16888	13757	1664	2465	1207
OVERALL AVERAGE=	5935						

YEAR= 1968

STATION #	1	2	3	4	5	6	7
MAY	2400	2300	3100	4300	200	500	800
JUNE	3175	3025	2500	4500	825	900	725
JULY	340	7720	1280	5460	1020	1080	820
AUGUST	18500	14667	62000	41133	26867	667	1000
SEPTEMBER	4800	15100	60333	171167	5133	4733	1433
OCTOBER	2150	7500	9675	52750	3700	1625	1450
NOVEMBER	1000	1400	8000	40000	56000	700	4000
AVERAGE	4624	7387	20984	45616	13274	1458	1461
OVERALL AVERAGE=	13543						

YEAR= 1969

STATION #	1	2	3	4	5	6	7
MAY	3050	20500	15500	2400	1000	1000	1150
JUNE	2600	10550	8750	7333	2325	2450	8750
JULY	316	6980	2200	1760	620	280	120
AUGUST	5200	1833	62333	12200	6467	7533	1200
SEPTEMBER	587	5227	45217	17417	2033	633	567
OCTOBER	133	4300	64667	32867	2667	2767	867
NOVEMBER	500	22000	2000	300000	1200	14000	3100
AVERAGE	1769	10199	28667	53425	2330	4095	2251
OVERALL AVERAGE=	14767						

YEAR= 1970

STATION #	1	2	3	4	5	6	7
JUNE	620	833	2367	1000	767	360	600
JULY	262	1300	2100	16933	700	283	1027
AUGUST	1467	5133	210000	23000	11733	1473	773
SEPTEMBER	330	3200	2133	26667	600	315	100
OCTOBER	470	1200	1600	3300	400	350	120
AVERAGE	630	2333	43640	14180	2840	556	524
OVERALL AVERAGE=	9243						

COLI

YEAR= 1971

STATION #	1	2	3	4	5	6	7
MARCH	ND	0	0	1600	0	0	0
MAY	750	200	300	15100	125	130	55
JUNE	110	2225	250	1100	45	90	85
JULY	100	750	470	350	180	345	40
AUGUST	230	675	327	3225	1107	240	92
SEPTEMBER	540	2000	4400	300	110	300	380
NOVEMBER	ND	ND	4000	ND	15000	7300	6800
DECEMBER	200	350	2875	1600	1350	800	275

AVERAGE	322	886	1578	3325	2240	1151	966
OVERALL AVERAGE=	1495						

YEAR= 1972

STATION #	1	2	3	4	5	6	7
JANUARY	60	1100	1100	2100	1700	220	200
FEBRUARY	ND	310	750	2800	480	250	330
MARCH	0	210	1220	1650	0	10	0
APRIL	10	1500	1800	5800	1000	30	10
JUNE	2900	600	27000	2900	1500	5100	200
JULY	1500	5280	192400	6480	1500	3700	303
AUGUST	4800	14933	20333	34333	4333	1567	2100
OCTOBER	ND	ND	700	28000	ND	1100	1000
DECEMBER	2800	2200	6600	8000	4200	300	1900

AVERAGE	1724	3263	27989	10229	1839	1365	671
OVERALL AVERAGE=	6726						

YEAR= 1973

STATION #	1	2	3	4	5	6	7
JANUARY	1000	300	300	5000	1000	1300	300
MARCH	7200	700	2200	4100	2600	600	700
APRIL	200	400	55000	200000	190000	400	100
MAY	100	1500	69000	29200	3500	200	2900
JUNE	2005	3375	430000	99000	14075	5100	1325
JULY	4000	4750	710000	425000	7200	18500	5400

AVERAGE	2418	1838	211083	127050	36395	2683	1788
OVERALL AVERAGE=	54751						

YEAR= 1974

STATION #	1	2	3	4	5	6	7
JUNE	2700	9033	7217	5833	3260	4483	3000
JULY	1058	16626	407120	103740	22920	20175	28567
AUGUST	4625	14475	795000	37250	6100	1900	9750
SEPTEMBER	2275	6800	171650	7675	4225	1750	420
OCTOBER	2781	5740	25040	15130	9940	3180	7360
NOVEMBER	1533	5300	4500	38900	1867	1100	1503
DECEMBER	900	13850	1150	13000	650	735	825

AVERAGE	3125	10261	201668	31647	6994	4760	7346
OVERALL AVERAGE=	37972						

COLI

YEAR= 1975

STATION #	1	2	3	4	5	6	7
JANUARY	800	ND	2200	9000	1500	270	390
APRIL	940	1047	33667	10580	ND	4343	220
MAY	700	1600	6600	6733	1250	4950	1665
JUNE	1073	5933	40400	16000	30700	2327	2633
JULY	2042	5340	70775	14840	2950	2042	20548
AUGUST	4325	9475	18950	26600	8523	910	3025
SEPTEMBER	15100	5925	14375	2875	2425	1475	1500
OCTOBER	4200	24833	4667	32333	2933	4200	2200
NOVEMBER	2367	9400	21333	29035	35500	8533	11567

AVERAGE	3506	7944	23660	16444	10723	3228	4839
OVERALL AVERAGE=	10049						

YEAR= 1976

STATION #	1	2	3	4	5	6	7
MAY	520	6050	5150	1000	5655	500	850
JUNE	8100	52500	46950	3690	235	740	735
JULY	11500	22475	14200	36167	16300	23800	24633
AUGUST	1152	5105	39850	18425	3425	1600	1475
SEPTEMBER	650	1624	26500	26625	300	875	625
OCTOBER	803	4267	3667	10717	7467	1663	807
NOVEMBER	670	34376	3677	19633	1267	1197	924

AVERAGE	3342	22342	19999	16608	4769	4339	4293
OVERALL AVERAGE=	10813						

YEAR= 1977

STATION #	1	2	3	4	5	6	7
MAY	5320	2700	57500	10500	7100	735	535
JUNE	3128	28074	40000	21320	2214	1340	270
JULY	1033	5525	65500	36900	1653	900	559
AUGUST	1240	39560	78399	44350	15800	4140	1310
SEPTEMBER	5133	43466	30667	33867	14433	4333	3257
OCTOBER	3550	51050	4650	4450	3550	4000	1900
NOVEMBER	4475	26275	22200	79000	1575	4325	1275

AVERAGE	3411	28093	42702	32912	6618	2825	1301
OVERALL AVERAGE=	16837						

YEAR= 1978

STATION #	1	2	3	4	5	6	7
JUNE	1117	10933	37633	73333	1500	1017	550
JULY	888	2975	1625	15150	405	550	25235
AUGUST	676	11540	21525	52200	4165	1064	264
SEPTEMBER	1655	9700	3000	53250	830	1000	410
OCTOBER	967	10067	10500	26733	1673	1037	707
NOVEMBER	1700	9000	11000	18000	1700	950	1000

AVERAGE	1000	9036	14214	39778	1712	936	4694
OVERALL AVERAGE=	10196						

COLI

YEAR= 1979

STATION #	1	2	3	4	5	6	7
MAY	950	10100	8100	1400	1950	365	350
JUNE	275	8250	10975	1525	318	530	215
JULY	6490	29150	14900	9900	4325	3893	3663
AUGUST	2524	29120	11420	24260	1564	1498	2000
SEPTEMBER	775	19675	11300	9675	1513	900	710
OCTOBER	4967	30333	15000	18667	2633	3067	2400
NOVEMBER	3200	3300	22450	2750	6500	1600	500
AVERAGE	2740	18561	13449	9740	2686	1693	1405
OVERALL AVERAGE=	7182						

STATION #	1	2	3	4	5	6	7
MAY	250	1200	1400	150	110	300	50
JUNE	150	1000	70	200	200	110	100
JULY	200	1000	500	100	50	70	100
AUGUST	50	200	500	100	100	110	100
SEPTEMBER	100	1100	100	50	100	110	50
OCTOBER	700						
NOVEMBER							
AVERAGE	140	1100	1000	400	200	110	50
OVERALL AVERAGE=	700						

STATION #	1	2	3	4	5	6	7
MAY	50	200	100	100	100	100	100
JUNE	10	50	100	100	10	10	10
JULY	100	100	100	100	100	100	100
AUGUST	100	100	100	100	100	100	100
SEPTEMBER	100	100	100	100	100	100	100
OCTOBER	100	100	100	100	100	100	100
NOVEMBER	100	100	100	100	100	100	100
AVERAGE	50	100	100	100	100	100	100
OVERALL AVERAGE=	50						

STATION #	1	2	3	4	5	6	7
MAY	100	50	50	100	100	50	50
JUNE	100	50	100	100	100	100	100
JULY	100	100	100	100	100	100	100
AUGUST	100	100	100	100	100	100	100
SEPTEMBER	100	100	100	100	100	100	100
OCTOBER	100	100	100	100	100	100	100
NOVEMBER	100	100	100	100	100	100	100
AVERAGE	100	100	100	100	100	100	100
OVERALL AVERAGE=	100						

FECAL COLI

YEAR= 1968

STATION #	1	2	3	4	5	6	7
MAY	50	60	130	80	0	10	0
JUNE	392	467	512	3150	22	47	32
JULY	96	504	190	968	44	52	130
AUGUST	1432	1680	4200	903	43	33	85
SEPTEMBER	523	923	3150	750	283	170	47
OCTOBER	90	1200	830	6742	550	212	60
NOVEMBER	130	3200	2300	4500	7200	90	2800

AVERAGE	388	1148	1616	2442	1163	88	451
OVERALL AVERAGE=	1042						

YEAR= 1969

STATION #	1	2	3	4	5	6	7
MAY	350	1050	1400	150	115	300	50
JUNE	1628	2000	90	283	390	115	1010
JULY	564	1060	525	1270	574	75	192
AUGUST	40	300	5250	1000	150	110	1000

AVERAGE	646	1103	1816	676	307	150	563
OVERALL AVERAGE=	752						

YEAR= 1970

STATION #	1	2	3	4	5	6	7
JUNE	20	233	1300	297	120	180	197
JULY	24	50	500	223	35	57	87
AUGUST	130	967	6300	580	230	177	210
SEPTEMBER	40	900	567	7093	283	77	53
OCTOBER	40	730	1000	700	180	70	12

AVERAGE	51	576	1933	1779	170	112	112
OVERALL AVERAGE=	676						

YEAR= 1971

STATION #	1	2	3	4	5	6	7
MARCH	ND	0	0	50	10	0	0
MAY	15	90	1205	2000	25	10	25
JUNE	40	610	95	420	5	10	70
JULY	10	210	15500	240	95	110	120
AUGUST	20	237	170	692	35	47	2
SEPTEMBER	140	1300	40000	50000	3000	80	60
NOVEMBER	ND	ND	850	ND	2700	1000	1700
DECEMBER	0	50	350	50	25	25	75

AVERAGE	38	357	7271	7636	737	160	257
OVERALL AVERAGE=	2351						

FECAL COLI

YEAR= 1972

STATION #	1	2	3	4	5	6	7
JANUARY	0	10	0	200	80	10	20
FEBRUARY	ND	0	290	620	270	70	10
MARCH	0	10	130	830	0	0	0
APRIL	0	0	90	670	0	0	0
JUNE	210	140	500	790	250	90	10
JULY	67	1760	8550	500	242	145	10
AUGUST	2437	1657	4033	2440	123	133	43
OCTOBER	ND	ND	10	20	0	0	0
DECEMBER	130	90	590	1120	80	40	40

AVERAGE	406	458	1577	799	116	54	15
OVERALL AVERAGE=	489						

YEAR= 1973

STATION #	1	2	3	4	5	6	7
JANUARY	0	30	40	900	250	120	20
MARCH	0	60	140	270	110	70	50
APRIL	0	120	4600	20000	50	10	40
MAY	10	20	0	980	450	10	120
JUNE	30	640	20425	14325	357	540	115
JULY	10	390	38500	650	70	225	20

AVERAGE	8	210	10618	6188	215	163	61
OVERALL AVERAGE=	2495						

YEAR= 1974

STATION #	1	2	3	4	5	6	7
JUNE	103	763	667	737	97	260	327
JULY	108	742	9840	2622	186	223	223
AUGUST	43	340	2013	4543	1350	88	267
SEPTEMBER	23	126	3935	70	123	160	90
OCTOBER	56	1086	332	762	955	162	150
NOVEMBER	67	1277	710	3920	183	77	140
DECEMBER	90	1180	220	480	150	30	100

AVERAGE	70	787	2531	1876	435	143	185
OVERALL AVERAGE=	861						

YEAR= 1975

STATION #	1	2	3	4	5	6	7
JANUARY	40	70	460	600	150	40	70
APRIL	10	303	4810	2203	ND	200	7
MAY	60	680	1850	4750	460	1250	260
JUNE	47	310	35933	2300	9400	403	800
JULY	104	624	7900	1208	330	426	2178
AUGUST	115	1695	1125	3550	143	65	273
SEPTEMBER	930	560	2100	938	323	758	195
OCTOBER	310	3520	577	735	347	480	160
NOVEMBER	180	900	777	1500	10600	1167	1133

AVERAGE	200	962	5937	1976	2719	532	564
OVERALL AVERAGE=	1841						

FECAL COLI

YEAR= 1976

STATION #	1	2	3	4	5	6	7
MAY	0	750	175	80	180	5	85
JUNE	223	600	1125	1200	13	103	73
JULY	50	447	95	625	900	1540	1697
AUGUST	5	188	1093	928	463	148	115
SEPTEMBER	18	525	2295	10593	5	30	48
OCTOBER	7	120	207	370	130	20	57
NOVEMBER	7	487	193	1163	110	103	77
AVERAGE	44	445	740	2137	257	278	307
OVERALL AVERAGE=	601						

YEAR= 1977

STATION #	1	2	3	4	5	6	7
MAY	45	115	870	1650	275	30	60
JUNE	90	1368	7680	815	498	146	28
JULY	7	320	6288	2125	148	38	275
AUGUST	44	7066	42540	1658	204	148	56
SEPTEMBER	233	2760	2200	2033	645	313	383
OCTOBER	265	4505	450	600	210	50	160
NOVEMBER	143	1613	570	18025	100	230	110
AVERAGE	118	2535	8657	3844	297	130	153
OVERALL AVERAGE=	2249						

YEAR= 1978

STATION #	1	2	3	4	5	6	7
JUNE	75	680	767	4333	50	70	30
JULY	113	200	367	3450	40	73	25060
AUGUST	114	1694	2200	20260	653	264	54
SEPTEMBER	160	1375	300	50600	365	320	35
OCTOBER	237	2100	1393	3033	383	343	120
NOVEMBER	280	1850	3150	5100	265	160	215
AVERAGE	140	1317	1363	14463	293	205	4252
OVERALL AVERAGE=	3148						

YEAR= 1979

STATION #	1	2	3	4	5	6	7
MAY	105	1075	680	75	80	120	10
JUNE	15	448	548	50	88	63	23
JULY	26	1118	650	973	83	80	123
AUGUST	62	1894	1096	3822	80	1076	32
SEPTEMBER	155	3275	4560	513	173	35	65
OCTOBER	1027	6467	4100	1833	470	727	355
NOVEMBER	300	1100	300	600	100	200	ND
AVERAGE	241	2197	1705	1124	153	230	101
OVERALL AVERAGE=	822						

CHLORIDE

YEAR= 1936

STATION #	1	2	3	4	5	6	7
JULY	20	26	20	20	20	20	19
AUGUST	20	21	23	20	19	20	20
SEPTEMBER	20	25	33	21	22	20	20
AVERAGE	20	24	25	20	20	20	20
OVERALL AVERAGE=	21						

YEAR= 1937

STATION #	1	2	3	4	5	6	7
JULY	19	20	22	21	21	21	18
AUGUST	19	20	22	21	21	19	22
SEPTEMBER	21	20	23	24	22	22	21
AVERAGE	20	20	22	22	21	21	20
OVERALL AVERAGE=	21						

YEAR= 1938

STATION #	1	2	3	4	5	6	7
JULY	20	20	32	24	24	23	23
AUGUST	21	21	24	25	22	23	25
SEPTEMBER	21	21	24	22	22	23	21
AVERAGE	21	21	27	24	23	23	23
OVERALL AVERAGE=	23						

YEAR= 1939

STATION #	1	2	3	4	5	6	7
JULY	19	20	22	22	20	21	22
AUGUST	20	21	38	21	21	23	20
SEPTEMBER	20	21	25	ND	ND	ND	20
AVERAGE	20	21	28	22	21	22	21
OVERALL AVERAGE=	22						

YEAR= 1940

STATION #	1	2	3	4	5	6	7
JULY	22	21	28	24	23	23	23
AUGUST	24	24	30	27	25	25	25
SEPTEMBER	24	23	26	29	26	25	25
AVERAGE	23	23	28	27	25	24	24
OVERALL AVERAGE=	25						

CHLORIDE

YEAR= 1948

STATION #	1	2	3	4	5	6	7
AVERAGE	ND	ND	ND	ND	ND	23	23
OVERALL AVERAGE=	23						

YEAR= 1962

STATION #	1	2	3	4	5	6	7
JUNE	39	42	44	43	40	41	41
JULY	39	40	41	41	40	40	39
AUGUST	38	39	45	40	38	38	37
AVERAGE	39	40	43	41	39	40	39
OVERALL AVERAGE=	40						

YEAR= 1963

STATION #	1	2	3	4	5	6	7
MAY	40	42	42	44	40	41	41
JUNE	34	36	37	39	36	36	34
JULY	38	39	40	41	38	37	38
AUGUST	34	35	37	37	34	34	33
SEPTEMBER	33	34	36	38	33	33	34
AVERAGE	36	37	38	40	36	36	36
OVERALL AVERAGE=	37						

YEAR= 1967

STATION #	1	2	3	4	5	6	7
MAY	43	45	44	46	40	42	42
JUNE	46	48	52	52	47	47	48
JULY	51	52	58	55	52	51	52
AUGUST	45	48	53	51	47	46	47
SEPTEMBER	42	45	46	48	44	43	42
OCTOBER	39	39	46	42	41	40	40
AVERAGE	44	46	52	49	45	45	45
OVERALL AVERAGE=	47						

YEAR= 1968

STATION #	1	2	3	4	5	6	7
MAY	48	49	53	50	48	47	48
JUNE	48	50	53	53	50	49	49
JULY	44	48	52	51	49	48	47
AUGUST	36	39	43	43	38	39	39
SEPTEMBER	37	54	43	44	38	39	38
OCTOBER	36	37	44	43	38	37	37
NOVEMBER	17	18	20	21	19	17	18
AVERAGE	38	42	44	44	40	39	39
OVERALL AVERAGE=	41						

CHLORIDE

YEAR= 1969

STATION #	1	2	3	4	5	6	7
MAY	53	60	65	62	59	59	58
JUNE	48	52	56	58	52	50	50
JULY	51	54	59	63	54	52	52
AUGUST	52	53	60	60	56	54	54
SEPTEMBER	47	46	57	55	51	52	46
OCTOBER	41	44	52	50	43	42	42

AVERAGE	49	52	58	58	53	52	50
OVERALL AVERAGE=	53						

YEAR= 1970

STATION #	1	2	3	4	5	6	7
JUNE	64	68	70	72	69	66	63
JULY	52	56	62	62	57	56	56
AUGUST	48	51	56	58	51	52	51
SEPTEMBER	43	46	62	52	46	44	43
OCTOBER	45	49	52	56	49	47	45

AVERAGE	50	54	60	60	54	53	52
OVERALL AVERAGE=	55						

YEAR= 1971

STATION #	1	2	3	4	5	6	7
MARCH	ND	96	112	128	122	126	122
MAY	60	70	67	83	62	61	63
JUNE	61	65	104	71	65	62	63
JULY	59	60	64	65	63	62	64
AUGUST	52	54	61	62	55	53	53
SEPTEMBER	50	59	58	65	59	57	58
NOVEMBER	ND	ND	52	ND	53	50	50
DECEMBER	51	51	52	61	50	52	51

AVERAGE	56	65	71	76	66	65	66
OVERALL AVERAGE=	66						

YEAR= 1972

STATION #	1	2	3	4	5	6	7
JANUARY	53	54	53	60	53	54	52
FEBRUARY	ND	62	63	62	60	58	57
MARCH	56	62	77	71	66	64	62
APRIL	61	67	74	81	69	63	63
JUNE	64	67	76	75	67	65	65
JULY	60	62	70	69	61	61	61
AUGUST	54	62	69	72	62	60	60
OCTOBER	46	ND	57	65	53	47	49
NOVEMBER	56	52	84	54	55	51	49
DECEMBER	53	53	61	78	57	56	55

AVERAGE	56	59	68	69	60	58	57
OVERALL AVERAGE=	61						

CHLORIDE

YEAR= 1973

STATION #	1	2	3	4	5	6	7
JANUARY	62	66	63	62	61	62	64
MARCH	55	57	67	69	61	59	58
APRIL	60	63	73	94	65	64	62
MAY	58	59	59	64	60	60	60
JUNE	47	83	73	76	63	62	61
JULY	62	62	73	76	61	62	62
AVERAGE	57	65	68	74	62	62	61
OVERALL AVERAGE=	64						

YEAR= 1974

STATION #	1	2	3	4	5	6	7
JUNE	56	62	64	70	60	59	58
JULY	55	59	66	67	58	56	56
AUGUST	53	53	61	62	56	54	52
SEPTEMBER	51	52	59	62	52	51	51
OCTOBER	45	46	57	52	47	46	45
NOVEMBER	48	50	65	56	49	49	48
DECEMBER	53	54	82	77	49	50	50
AVERAGE	52	54	65	64	53	52	51
OVERALL AVERAGE=	56						

YEAR= 1975

STATION #	1	2	3	4	5	6	7
JANUARY	55	55	75	70	56	58	56
APRIL	57	65	75	72	ND	63	65
MAY	65	65	72	74	69	66	65
JUNE	63	66	74	72	70	68	65
JULY	60	61	69	71	62	61	60
AUGUST	52	52	59	64	57	53	53
SEPTEMBER	45	47	58	53	47	47	47
OCTOBER	47	47	56	61	49	46	46
NOVEMBER	44	47	57	55	53	52	43
AVERAGE	54	56	66	66	58	57	56
OVERALL AVERAGE=	59						

YEAR= 1976

STATION #	1	2	3	4	5	6	7
MAY	59	62	74	72	65	64	62
JUNE	60	61	79	53	64	64	63
JULY	58	62	67	66	63	62	58
AUGUST	55	59	69	74	58	57	56
SEPTEMBER	50	51	66	67	55	53	54
OCTOBER	45	50	60	62	51	48	46
NOVEMBER	48	52	68	72	51	50	48
AVERAGE	54	57	69	67	58	57	55
OVERALL AVERAGE=	60						

CHLORIDE

YEAR= 1977

STATION #	1	2	3	4	5	6	7
MAY	69	72	87	97	75	70	69
JUNE	65	69	85	83	68	65	65
JULY	59	60	67	71	58	58	60
AUGUST	50	66	66	60	54	52	52
SEPTEMBER	49	53	69	54	50	50	50
OCTOBER	48	50	67	56	46	46	45
NOVEMBER	40	49	57	71	49	47	48

AVERAGE	55	60	71	70	57	55	56
OVERALL AVERAGE=	61						

YEAR= 1978

STATION #	1	2	3	4	5	6	7
JUNE	65	67	76	85	68	67	67
JULY	62	64	67	67	63	63	62
AUGUST	51	54	62	63	54	53	52
SEPTEMBER	47	48	54	55	49	44	47
OCTOBER	49	48	57	55	47	45	46
NOVEMBER	46	48	57	60	52	47	46

AVERAGE	53	55	62	64	56	53	53
OVERALL AVERAGE=	57						

YEAR= 1979

STATION #	1	2	3	4	5	6	7
MAY	68	71	89	85	73	69	69
JUNE	64	67	84	83	69	66	66
JULY	79	78	91	85	79	78	79
AUGUST	54	56	71	66	58	55	56
SEPTEMBER	53	56	70	63	54	54	54
OCTOBER	49	53	77	59	55	52	52
NOVEMBER	39	53	68	65	55	53	53

AVERAGE	58	62	79	72	63	61	61
OVERALL AVERAGE=	65						

NITRATE

YEAR= 1948

STATION #	1	2	3	4	5	6	7
AVERAGE	ND	ND	ND	ND	ND	0.45	0.35
OVERALL AVERAGE=	0.40						

YEAR= 1958

STATION #	1	2	3	4	5	6	7
MAY	ND	ND	ND	ND	ND	0.34	0.44
JUNE	0.36	ND	0.31	ND	0.27	0.25	0.26
JULY	0.42	ND	0.37	ND	0.37	0.28	0.38
AUGUST	0.46	ND	0.57	ND	0.56	0.55	0.51
SEPTEMBER	0.48	ND	0.57	ND	0.48	0.45	0.46
OCTOBER	ND	ND	ND	ND	ND	0.39	ND
NOVEMBER	ND	ND	ND	ND	ND	0.44	ND
AVERAGE	0.43	ND	0.46	ND	0.42	0.38	0.41
OVERALL AVERAGE=	0.42						

YEAR= 1961

STATION #	1	2	3	4	5	6	7
APRIL	1.13	1.00	1.00	1.17	1.13	1.37	0.87
MAY	1.10	1.08	1.12	1.04	1.00	0.96	1.00
JUNE	0.73	0.80	1.00	0.67	0.73	0.87	0.87
JULY	1.93	2.20	1.80	1.73	1.93	2.07	1.93
AVERAGE	1.22	1.27	1.23	1.15	1.20	1.32	1.17
OVERALL AVERAGE=	1.22						

YEAR= 1963

STATION #	1	2	3	4	5	6	7
JUNE	0.68	0.74	0.70	0.58	0.69	0.66	0.64
JULY	1.86	1.81	ND	1.70	1.86	ND	1.85
SEPTEMBER	1.96	1.93	1.90	1.25	1.97	1.96	2.02
AVERAGE	1.50	1.49	1.30	1.18	1.51	1.31	1.50
OVERALL AVERAGE=	1.40						

YEAR= 1964

STATION #	1	2	3	4	5	6	7
JUNE	0.72	0.66	1.05	0.86	0.65	0.66	0.68
JULY	0.60	0.59	0.89	0.57	0.57	0.69	0.74
AUGUST	0.73	0.75	1.02	0.92	0.78	0.84	0.97
SEPTEMBER	0.66	0.64	0.83	0.74	0.71	0.78	0.95
OCTOBER	1.14	0.98	1.64	0.70	1.32	1.89	1.77
NOVEMBER	2.20	2.08	2.03	1.16	1.90	2.54	2.59
AVERAGE	1.01	0.95	1.24	0.83	0.99	1.23	1.28
OVERALL AVERAGE=	1.08						

NITRATE

YEAR= 1965

STATION #	1	2	3	4	5	6	7
MAY	0.39	0.44	0.75	0.58	0.60	0.56	0.25
JUNE	0.27	0.23	0.61	0.49	0.41	0.50	0.48
JULY	2.68	2.73	2.45	2.33	2.50	2.65	ND
AUGUST	2.20	2.70	2.13	1.68	2.20	2.45	2.63
SEPTEMBER	1.60	1.50	1.60	1.18	1.65	1.60	1.75
OCTOBER	2.55	2.20	2.90	1.70	2.50	2.70	2.95

AVERAGE	1.62	1.63	1.74	1.33	1.64	1.74	1.61
OVERALL AVERAGE=	1.62						

YEAR= 1966

STATION #	1	2	3	4	5	6	7
AUGUST	1.13	1.00	1.30	0.60	1.14	1.00	1.51
SEPTEMBER	1.53	1.25	1.55	1.40	1.40	1.33	1.43
OCTOBER	0.70	0.55	0.55	0.65	0.50	0.50	0.50

AVERAGE	1.12	0.93	1.13	0.88	1.01	0.94	1.16
OVERALL AVERAGE=	1.02						

YEAR= 1967

STATION #	1	2	3	4	5	6	7
APRIL	ND	ND	ND	ND	ND	ND	0.00
MAY	1.20	1.18	1.23	0.95	1.13	1.28	1.30
JUNE	1.33	1.38	1.38	1.06	1.41	1.30	1.28
JULY	3.93	4.05	3.80	3.92	3.37	3.98	3.83
AUGUST	4.01	3.36	3.63	3.65	4.23	4.31	4.26
SEPTEMBER	2.00	1.93	1.80	1.50	1.83	1.98	1.85
OCTOBER	1.20	0.90	1.45	0.85	1.18	1.23	1.20

AVERAGE	2.28	2.13	2.22	1.99	2.19	2.35	2.29
OVERALL AVERAGE=	2.21						

YEAR= 1968

STATION #	1	2	3	4	5	6	7
MAY	0.80	0.70	0.60	0.55	0.70	0.70	0.70
JUNE	0.65	0.64	0.62	0.50	0.65	0.62	0.64
JULY	2.10	2.00	1.74	1.63	1.90	1.83	2.04
AUGUST	1.70	1.65	1.43	1.34	1.53	1.64	1.84
SEPTEMBER	1.05	1.10	0.87	0.78	1.11	1.23	1.25
OCTOBER	0.84	1.13	1.63	0.40	0.71	0.96	0.91
NOVEMBER	0.53	0.53	0.54	0.45	0.51	0.52	0.54

AVERAGE	1.10	1.11	1.06	0.81	1.02	1.07	1.13
OVERALL AVERAGE=	1.04						

NITRATE

YEAR= 1969

STATION #	1	2	3	4	5	6	7
MAY	0.65	0.60	0.65	0.51	0.60	0.62	0.63
JUNE	0.74	0.89	0.79	0.69	0.96	0.81	0.99
JULY	1.85	1.97	1.70	1.63	1.75	1.94	1.98
AUGUST	1.71	1.78	1.61	1.25	1.83	1.82	1.79
SEPTEMBER	1.40	1.38	1.24	1.10	1.36	1.47	1.45
OCTOBER	1.17	0.92	0.93	0.64	0.80	0.93	0.89

AVERAGE	1.25	1.26	1.15	0.97	1.22	1.27	1.29
OVERALL AVERAGE=	1.20						

YEAR= 1970

STATION #	1	2	3	4	5	6	7
JUNE	0.92	0.91	0.81	0.38	0.98	1.07	1.07
JULY	2.09	2.25	2.00	2.00	2.59	2.48	2.70
AUGUST	2.02	2.19	1.84	1.60	1.88	2.00	1.97
SEPTEMBER	1.72	1.91	0.98	1.43	1.59	1.67	1.81
OCTOBER	2.20	2.15	2.00	1.45	1.40	2.30	2.45

AVERAGE	1.79	1.88	1.53	1.37	1.69	1.90	2.00
OVERALL AVERAGE=	1.74						

YEAR= 1971

STATION #	1	2	3	4	5	6	7
MARCH	ND	0.95	1.45	1.25	1.25	0.60	1.35
MAY	1.50	1.21	1.12	0.32	1.42	1.30	1.30
JUNE	1.40	1.45	2.12	1.29	1.41	1.48	1.50
JULY	2.33	2.23	2.04	1.91	2.30	2.35	2.41
AUGUST	2.30	2.32	2.15	1.70	2.17	1.76	1.85
SEPTEMBER	1.90	1.80	1.60	0.05	1.60	1.75	1.80
NOVEMBER	ND	ND	2.80	ND	2.80	3.00	3.10
DECEMBER	1.42	2.25	2.46	1.90	2.04	2.40	2.67

AVERAGE	1.81	1.74	1.97	1.20	1.87	1.83	2.00
OVERALL AVERAGE=	1.77						

YEAR= 1972

STATION #	1	2	3	4	5	6	7
JANUARY	1.05	1.40	1.40	1.90	1.75	1.45	0.90
FEBRUARY	ND	0.85	1.10	1.20	0.85	0.55	0.77
MARCH	1.45	1.55	1.50	1.30	1.45	1.55	1.55
APRIL	1.10	1.70	0.65	0.95	1.20	1.95	1.30
JUNE	1.88	1.54	1.54	0.96	1.66	1.68	1.63
JULY	1.93	2.10	1.70	1.70	1.90	2.00	2.21
AUGUST	1.90	2.10	2.00	1.36	2.04	2.17	2.00
OCTOBER	2.20	2.25	1.65	1.25	1.70	2.35	2.35
NOVEMBER	2.90	3.05	2.10	2.75	2.85	3.00	3.00
DECEMBER	2.75	2.90	2.60	2.70	3.10	2.75	2.80

AVERAGE	1.91	1.94	1.68	1.61	1.85	1.95	1.86
OVERALL AVERAGE=	1.83						

NITRATE

YEAR= 1973

STATION #	1	2	3	4	5	6	7
JANUARY	2.05	2.10	2.17	1.75	1.98	1.98	2.10
MARCH	1.60	1.70	1.80	1.60	1.85	1.55	1.70
APRIL	1.46	1.38	1.20	1.20	1.26	1.56	1.32
MAY	1.16	1.30	1.30	1.00	1.36	1.36	1.30
JUNE	2.21	2.14	1.80	0.48	2.13	2.09	1.93
JULY	1.80	2.02	1.35	1.08	1.90	1.95	2.23

AVERAGE	1.71	1.77	1.60	1.19	1.75	1.75	1.76
OVERALL AVERAGE=	1.65						

YEAR= 1974

STATION #	1	2	3	4	5	6	7
JUNE	1.02	1.43	1.42	0.90	1.61	1.54	1.63
JULY	2.65	2.33	2.00	1.79	2.40	2.37	2.26
AUGUST	2.85	2.50	2.53	2.40	2.30	2.48	2.45
SEPTEMBER	2.15	2.33	2.18	2.60	2.40	2.11	2.35
OCTOBER	1.84	1.47	1.36	1.30	1.54	1.52	1.80
NOVEMBER	2.20	2.15	1.90	2.15	2.10	2.10	2.20
DECEMBER	1.40	2.00	1.80	1.98	1.98	2.03	2.00

AVERAGE	2.02	2.03	1.88	1.87	2.05	2.02	2.10
OVERALL AVERAGE=	2.00						

YEAR= 1975

STATION #	1	2	3	4	5	6	7
JANUARY	1.20	1.10	1.05	1.05	1.05	1.15	1.10
APRIL	1.42	1.45	1.32	1.31	ND	1.38	1.50
MAY	1.22	1.22	1.38	1.24	1.30	1.23	1.22
JUNE	1.07	1.08	1.17	1.14	1.02	0.95	1.03
JULY	1.86	1.93	1.78	1.90	1.94	2.02	1.77
AUGUST	1.91	1.92	1.82	2.45	1.90	1.94	1.89
SEPTEMBER	1.88	1.76	1.67	1.76	1.76	1.89	1.92
OCTOBER	0.88	0.88	0.97	0.98	1.03	0.88	1.20
NOVEMBER	1.55	1.62	1.20	1.58	1.87	2.38	2.08

AVERAGE	1.44	1.44	1.37	1.49	1.48	1.54	1.52
OVERALL AVERAGE=	1.47						

YEAR= 1976

STATION #	1	2	3	4	5	6	7
MAY	1.27	1.24	1.42	1.05	1.16	1.21	1.27
JUNE	1.73	1.70	1.74	1.17	1.61	1.61	1.58
JULY	2.10	2.05	2.05	1.79	2.00	2.03	2.03
AUGUST	1.71	1.70	1.75	1.31	1.67	1.74	1.73
SEPTEMBER	1.51	1.54	1.43	1.74	5.93	1.65	1.49
OCTOBER	1.80	1.72	2.02	1.52	1.73	1.57	2.18
NOVEMBER	2.05	2.05	2.00	1.45	1.85	2.05	2.05

AVERAGE	1.74	1.71	1.77	1.43	2.28	1.69	1.76
OVERALL AVERAGE=	1.77						

NITRATE

YEAR= 1977

STATION #	1	2	3	4	5	6	7
MAY	1.04	1.14	1.04	0.57	0.96	1.06	1.03
JUNE	1.02	1.13	1.26	1.32	1.13	1.14	1.29
JULY	2.37	2.33	2.33	2.68	2.35	2.41	2.37
AUGUST	1.67	1.84	1.55	1.97	1.89	1.70	1.77
SEPTEMBER	1.30	1.20	1.17	1.40	1.32	1.34	1.47
OCTOBER	2.15	2.00	2.20	2.20	2.30	2.20	2.30
NOVEMBER	1.77	2.07	2.07	2.20	2.05	1.93	2.05

AVERAGE	1.62	2.93	1.66	1.76	1.71	1.68	1.75
OVERALL AVERAGE=	1.87						

YEAR= 1978

STATION #	1	2	3	4	5	6	7
JUNE	1.87	1.88	2.28	3.47	2.07	2.07	1.94
JULY	2.27	2.04	2.26	2.35	2.29	2.21	2.29
AUGUST	1.76	1.70	1.72	3.07	1.80	1.76	1.75
SEPTEMBER	1.30	1.28	1.20	1.70	1.33	0.70	1.28
OCTOBER	1.07	1.57	1.75	2.29	1.80	1.76	1.23
NOVEMBER	1.40	1.00	1.80	2.00	1.80	0.80	1.00

AVERAGE	1.61	1.58	1.84	2.48	1.85	1.55	1.58
OVERALL AVERAGE=	1.78						

YEAR= 1979

STATION #	1	2	3	4	5	6	7
MAY	1.53	1.56	1.81	2.04	1.67	1.67	1.58
JUNE	1.84	1.79	1.93	2.65	2.04	1.92	1.89
JULY	2.54	2.43	2.45	3.15	2.55	2.60	2.40
AUGUST	2.18	2.28	2.20	3.06	2.44	2.28	2.14
SEPTEMBER	1.96	1.89	1.91	2.63	2.14	2.06	2.03
OCTOBER	4.30	2.50	1.80	4.10	2.30	2.40	2.45
NOVEMBER	3.58	3.45	3.38	3.75	3.60	3.40	3.10

AVERAGE	2.56	2.27	2.21	3.05	2.39	2.33	2.23
OVERALL AVERAGE=	2.43						

TOTAL P04

YEAR= 1948

STATION #	1	2	3	4	5	6	7
AVERAGE	ND	ND	ND	ND	ND	0.00	0.00
OVERALL AVERAGE=	0.00						

YEAR= 1963

STATION #	1	2	3	4	5	6	7
MAY	0.15	0.03	0.20	0.06	0.03	0.02	0.02
JUNE	0.25	0.02	0.07	0.10	0.02	0.03	0.02
JULY	0.03	0.04	0.08	0.07	0.03	0.03	0.03

AVERAGE	0.14	0.03	0.12	0.08	0.03	0.03	0.02
OVERALL AVERAGE=	0.06						

YEAR= 1965

STATION #	1	2	3	4	5	6	7
JUNE	0.07	0.06	0.05	0.19	0.05	0.06	0.06
JULY	0.06	0.12	0.07	0.25	0.09	0.07	ND
AUGUST	0.13	0.10	0.13	0.35	0.12	0.09	0.06

AVERAGE	0.09	0.09	0.08	0.26	0.09	0.07	0.06
OVERALL AVERAGE=	0.11						

YEAR= 1967

STATION #	1	2	3	4	5	6	7
MAY	0.35	0.25	0.35	1.05	0.40	0.45	0.35
JUNE	0.26	0.18	0.25	0.34	0.20	0.20	0.22
JULY	0.35	0.21	0.26	0.28	0.20	0.19	0.24
AUGUST	0.33	0.26	0.29	0.28	0.64	0.22	0.28
SEPTEMBER	0.43	0.36	0.25	0.63	0.37	0.21	0.33
OCTOBER	0.33	0.00	0.40	0.45	0.23	0.23	0.25

AVERAGE	0.34	0.24	0.30	0.51	0.34	0.25	0.28
OVERALL AVERAGE=	0.32						

YEAR= 1968

STATION #	1	2	3	4	5	6	7
MAY	0.09	0.09	0.11	0.10	0.01	0.02	0.03
JUNE	0.20	0.01	0.11	0.33	0.12	0.11	0.07
JULY	0.31	0.16	0.21	0.26	0.14	0.14	0.11
AUGUST	0.33	0.12	0.22	0.20	0.08	0.12	0.14
SEPTEMBER	0.29	0.19	0.27	0.30	0.23	0.14	0.17
OCTOBER	0.28	0.21	0.19	0.43	0.20	0.09	0.07

AVERAGE	0.25	0.13	0.19	0.27	0.13	0.10	0.10
OVERALL AVERAGE=	0.17						

TOTAL P04

YEAR= 1969

STATION #	1	2	3	4	5	6	7
MAY	0.29	0.14	0.23	0.49	0.21	2.55	2.55
JUNE	0.21	0.14	0.23	0.31	0.20	0.11	0.09
JULY	0.14	0.07	0.20	0.19	0.18	0.11	0.11
AUGUST	0.13	0.06	0.21	0.17	0.07	0.04	0.10
SEPTEMBER	0.19	0.25	0.42	0.40	0.32	0.14	0.18
OCTOBER	0.27	0.30	0.43	0.45	0.25	0.25	0.20

AVERAGE	0.21	0.14	0.29	0.34	0.21	0.53	0.54
OVERALL AVERAGE=	0.32						

YEAR= 1970

STATION #	1	2	3	4	5	6	7
JUNE	0.14	0.12	0.17	4.90	0.13	0.08	0.08
JULY	0.25	0.10	0.26	0.56	0.20	0.31	0.21
AUGUST	0.10	0.10	0.20	1.08	0.14	0.09	0.13
SEPTEMBER	0.06	0.29	0.34	0.61	0.33	0.07	0.06
OCTOBER	0.05	0.10	0.10	0.70	0.20	0.10	0.05

AVERAGE	0.12	0.14	0.21	1.57	0.20	0.13	0.11
OVERALL AVERAGE=	0.35						

YEAR= 1971

STATION #	1	2	3	4	5	6	7
MARCH	ND	0.10	0.15	0.40	0.20	0.15	0.25
MAY	0.07	0.14	0.22	4.10	0.30	0.12	0.10
JUNE	0.09	0.03	0.05	1.42	0.09	0.06	0.10
JULY	0.13	0.10	0.11	0.46	0.12	0.12	0.09
AUGUST	0.12	0.14	0.25	0.67	0.13	0.67	0.65
SEPTEMBER	0.05	0.05	0.10	1.65	0.15	0.10	0.05
NOVEMBER	ND	ND	0.20	ND	0.20	0.20	0.10
DECEMBER	0.10	0.17	0.15	0.30	0.16	0.13	0.11

AVERAGE	0.09	0.10	0.15	1.29	0.17	0.19	0.18
OVERALL AVERAGE=	0.31						

YEAR= 1972

STATION #	1	2	3	4	5	6	7
JANUARY	0.10	0.10	0.03	0.07	0.05	0.03	0.05
FEBRUARY	ND	0.05	0.07	0.08	0.07	0.05	0.03
MARCH	0.25	0.10	0.20	0.40	0.15	0.15	0.10
APRIL	0.10	0.10	0.15	0.25	0.25	0.15	0.10
JUNE	0.06	0.04	0.06	0.32	0.03	0.07	0.03
JULY	0.05	0.05	0.08	0.19	0.05	0.05	0.04
AUGUST	0.06	0.05	0.05	0.27	0.08	0.06	0.07
OCTOBER	ND	ND	0.06	0.11	0.04	0.03	0.04
NOVEMBER	0.03	0.03	0.03	0.18	0.03	0.02	0.03
DECEMBER	0.02	0.02	0.02	0.06	0.02	0.02	0.02

AVERAGE	0.08	0.06	0.08	0.19	0.08	0.06	0.05
OVERALL AVERAGE=	0.09						

TOTAL P04

YEAR= 1977

STATION #	1	2	3	4	5	6	7
MAY	0.04	0.40	0.06	0.17	0.55	0.04	0.04
JUNE	0.05	0.04	0.07	0.15	0.05	0.04	0.04
JULY	0.05	0.05	0.07	0.16	0.03	0.04	0.03
AUGUST	0.03	0.04	0.13	0.10	0.06	0.04	0.04
SEPTEMBER	0.05	0.04	0.12	0.17	0.06	0.07	0.05
OCTOBER	0.08	0.06	0.08	0.10	0.06	0.06	0.06
NOVEMBER	0.06	0.04	0.05	0.34	0.07	0.04	0.04

AVERAGE	0.05	0.10	0.08	0.17	0.13	0.05	0.04
OVERALL AVERAGE=	0.09						

YEAR= 1978

STATION #	1	2	3	4	5	6	7
JUNE	0.08	0.07	0.07	0.14	0.16	0.11	0.07
JULY	0.05	0.09	0.05	0.08	0.07	0.05	0.06
AUGUST	0.04	0.05	0.05	0.21	0.05	0.05	0.05
SEPTEMBER	0.01	0.05	0.03	0.15	0.04	0.01	0.01
OCTOBER	0.05	0.02	0.05	0.23	0.02	0.01	0.02
NOVEMBER	0.03	0.01	0.04	0.37	0.04	0.01	0.01

AVERAGE	0.04	0.05	0.05	0.20	0.06	0.04	0.04
OVERALL AVERAGE=	0.06						

YEAR= 1979

STATION #	1	2	3	4	5	6	7
MAY	0.14	0.11	0.10	0.37	0.13	0.14	0.16
JUNE	0.10	0.09	0.06	0.35	0.11	0.08	0.08
JULY	0.05	0.07	0.06	0.15	0.12	0.07	0.07
AUGUST	0.02	0.02	0.05	0.21	0.03	0.02	0.04
SEPTEMBER	0.11	0.12	0.07	0.20	0.09	0.06	0.06
OCTOBER	0.06	0.03	ND	0.22	0.04	0.04	0.02
NOVEMBER	0.07	0.05	0.07	0.18	0.09	0.06	0.06

AVERAGE	0.08	0.07	0.07	0.24	0.09	0.07	0.07
OVERALL AVERAGE=	0.10						

TOTAL P04

YEAR= 1973

STATION #	1	2	3	4	5	6	7
JANUARY	0.04	0.04	0.04	0.10	0.06	0.04	0.04
MARCH	0.16	0.10	0.08	0.14	0.14	0.10	0.10
APRIL	0.02	0.03	0.05	0.52	0.03	0.03	0.04
MAY	0.04	0.04	0.02	0.10	0.08	0.04	0.04
JUNE	0.02	0.04	0.06	0.37	0.02	0.08	0.02
JULY	0.05	0.11	0.08	0.18	0.04	0.03	0.05

AVERAGE	0.06	0.06	0.06	0.24	0.06	0.05	0.05
OVERALL AVERAGE=	0.08						

YEAR= 1974

STATION #	1	2	3	4	5	6	7
JUNE	0.08	0.12	0.12	0.20	0.04	0.10	0.12
JULY	0.08	0.05	0.09	0.07	0.09	0.08	0.06
AUGUST	0.06	0.06	0.08	0.07	0.05	0.06	0.05
SEPTEMBER	0.04	0.10	0.05	0.13	0.05	0.04	0.03
OCTOBER	0.08	0.07	0.05	0.07	0.06	0.12	0.05
NOVEMBER	0.09	0.07	0.08	0.08	0.06	0.05	0.06
DECEMBER	0.04	0.06	0.05	0.08	0.11	0.06	0.04

AVERAGE	0.07	0.08	0.07	0.10	0.07	0.07	0.06
OVERALL AVERAGE=	0.07						

YEAR= 1975

STATION #	1	2	3	4	5	6	7
JANUARY	0.10	0.10	0.14	0.20	0.60	0.06	0.06
APRIL	0.04	0.06	0.09	0.10	ND	0.05	0.04
MAY	0.03	0.02	0.05	0.07	0.04	0.01	0.02
JUNE	0.04	0.03	0.07	0.09	0.04	0.01	0.05
JULY	0.04	0.03	0.03	0.07	0.03	0.05	0.03
AUGUST	0.09	0.10	0.08	0.13	0.08	0.06	0.06
SEPTEMBER	0.06	0.36	0.04	0.07	0.05	0.05	0.05
OCTOBER	0.04	0.06	0.05	0.26	0.07	0.04	0.05
NOVEMBER	0.06	0.04	0.05	0.05	0.18	0.05	0.06

AVERAGE	0.06	0.09	0.07	0.12	0.14	0.05	0.05
OVERALL AVERAGE=	0.08						

YEAR= 1976

STATION #	1	2	3	4	5	6	7
MAY	0.16	0.22	0.20	0.91	0.17	0.11	0.15
JUNE	0.05	0.04	0.05	0.20	0.07	0.08	0.06
JULY	0.06	0.05	0.06	0.12	0.04	0.06	0.05
AUGUST	0.03	0.02	0.03	0.26	0.02	0.01	0.03
SEPTEMBER	0.02	0.03	0.04	0.18	0.03	0.03	0.03
OCTOBER	0.03	0.03	0.05	0.06	0.03	0.02	0.03
NOVEMBER	0.03	0.03	0.04	0.06	0.03	0.03	0.03

AVERAGE	0.05	0.06	0.07	0.26	0.03	0.05	0.05
OVERALL AVERAGE=	0.09						

"CHANGES IN THE AQUATIC BIOTA OF COOTES PARADISE MARSH"

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August, 1980

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1. INTRODUCTION

Recognizing the importance of understanding the biological relationships within Cootes Paradise Marsh as a prerequisite for its management, Dr. E. Warren of McMaster University in 1946 launched an ambitious, systematic study of Royal Botanical Gardens' property. Motivated by the lack of published information regarding the fauna and flora of the area he, and a half dozen researchers, commenced investigation of several separate, but interrelated, facets of Marsh ecology under the auspices of the Research Council of Ontario, now the Ontario Research Foundation. Their efforts resulted in several publications regarding the abundance and variety of marsh life during the late 1940s, (Judd 1948; Simms 1949; Kay 1949; Turner 1948; Warren 1950; Wragg 1953). In most of these studies the effects of water pollution were evident by certain changes already taking place in the Marsh flora and fauna. However, little management resulted and almost a quarter century passed before interest in Marsh ecology was re-established, again by researchers from McMaster University. Studies undertaken during the early 1970s by Dr. G. P. Harris proved that sewage from the Dundas Treatment Plant and silt from surrounding streams had degraded Cootes Paradise to the point that its usage as a wildlife sanctuary was in serious jeopardy (Harris and Bacchus 1947, Harris and Smith 1977). Therefore, in 1975 the Royal Botanical Gardens formulated a Policy Statement on Cootes Paradise and established Water Quality Guidelines (see appendix 1) in an effort to halt and eventually reverse the deteriorating trends which were occurring. The Regional Municipality of Hamilton-Wentworth adopted these two documents, pledging their commitment to improving water quality in the Marsh, and requested the Ontario Ministry of the Environment to conduct a study of Cootes Paradise and recommend programmes of water treatment which would be of benefit in attaining the goals advocated by Royal Botanical Gardens.

As a result of the M.O.E. study, (Semkin et al, 1976), an expanded and technologically upgraded sewage treatment facility in Dundas began operation in the fall of 1978. The Ontario Ministry of the Environment now monitors the quality of this effluent and other sources of pollutants and their combined effects on water quality in the Marsh. In 1978 the RBG began a companion programme to determine the response of the aquatic organisms to this change in input quality and to future pollution abatement measures. This resulted in several biological surveys being completed at that time. The intent of this report therefore, is to demonstrate the extent to which the deteriorated water quality has affected the flora and fauna by comparing present day surveys to those of the 1940s.

2. BIOLOGICAL EFFECTS OF ENVIRONMENTAL CHANGE

Organisms depend upon the conditions around them for survival and growth. Complex interrelationships develop among the species present and between them and those conditions. After a period of time this assemblage will take on well-

defined characteristics. It can then be considered a biological community. If the environmental conditions of the location change temporarily the community remains largely unaffected. If, however, the change is persistent, new species relationships are formed as populations of most species are either diminished, replaced or favoured by the change. The new community structure so formed is, therefore, a reflection of the conditions of the new environment.

3. BIOLOGICAL CHANGE IN COOTES PARADISE MARCH

Eutrophication is a term used to describe excessive natural or artificial addition of nutrients to a body of water and to the effects of these nutrients (Rohlich 1969). The effluent of the Dundas Sewage Treatment Plant has been the major contributor of nutrients to the Marsh (Semkin et al, 1976) and therefore, the main factor in its eutrophication. High levels of phosphorus and nitrogen, the two most important plant nutrients, have been supplied to the Marsh for decades by the Dundas Sewage Treatment Plant and are now in such elevated concentrations in both water and sediments as to sustain a persistent phytoplankton bloom throughout the summer months. The resultant mass of dead cell remains settling down to the bottom creates a high oxygen demand at the sediment-water interface. Under the hot calm days of summer frequent periods of complete anoxia occur. Such oxygen depletion is stated by Warren (1971) to be either directly or indirectly deleterious to the survival reproduction, growth and/or movement of fish and other organisms.

In addition to this, suspended and settled silt transported to Cootes Paradise by surrounding streams, particularly Spencer Creek, places additional stress on aquatic organisms by the following mode of action as outlined by Environment Canada (1978). Suspended and settled silt:

1. reduces light penetration restricting or eliminating photosynthesis
2. abrades biota, damaging respiratory and excretory organs
3. absorbs toxicants, resulting in transport and concentration of heavy metals, pesticides and nutrients
4. changes the bottom substrate resulting in the infilling of interstices between stones and the formation of unstable substrates

A 2-metre sediment core taken from Cootes Paradise in 1977 revealed that the bottom 150 cm consisted of plant remains and diatoms associated with marsh vegetation. However, these layers were overlain with approximately 50 cm of grey-brown clay. This tends to support the notion that sedimentation has been quite recent and related to the settlement of the Spencer Creek watershed. (Harris, pers. comm.)

The combination of high silt and nutrient loading create conditions which, further aggravated by high winds and the spawning and feeding activities of carp, are unsuitable for many types of organisms previously a part of the Marsh biota. As a result of the loss of certain species, the appearance of new ones and shifts in abundance of several, a Marsh flora and fauna, much reduced in diversity, dominated numerically by a few tolerant species, and characterized by high productivity, is now established. The subsequent community transformations have been extensive as the following comparative accounts illustrate.

(i) Phytoplankton

The phytoplankton is the assemblage of small plants, usually single cells, that have no or very limited powers of locomotion and are more or less subject to distribution by water movements (Wetzel 1975). Of the various biological components of an aquatic ecosystem they most clearly reflect the chemical changes in the water because they use the available minerals directly as a course of nutrition.

In 1947, Mr. R. A. Sims of McMaster University characterized the plankton flora of Cootes Paradise. He reported that the Chlorophyceae dominated the six classes, 55 genera and 116 species he found. This is still true today, however, only 44 genera are now represented with one species. Scenedesmus Quadricauda comprising up to 90 percent of the total cells counted at some stations. In addition, average cell numbers in open water between June 1 and August 16, 1949, were 5.8×10 cells/ml. while the 1978 and 1979 cell counts of 2.8×10^4 and 2.9×10^4 respectively, during the same time period, represent a five fold increase. A complete listing of phytoplankton species presently found in Cootes Paradise is shown in Appendix 2.

The success of S. quadricauda in a hypereutrophic environment such as Cootes Paradise is not unusual. This species was found to dominate in Moses Lake, Washington, by Bush and Welch (1972) where the N/P ratio was low and similar to that found in the western end of Cootes Paradise.

The abundance of members of the Euglenophyta in the Marsh is significant because this group is capable of heterotrophy i.e. the ability to utilize organic substrates as a source of nutrition. Wetzel (1975) emphasized that when very dense populations lead to self-shading, an ability to be facultatively heterotrophic can constitute a distinct competitive advantage over metabolism of obligate photoautotrophic algae (i.e. those dependent on photosynthesis). Palmer (1969) lists Euglena as the most pollution tolerant genus of algae. This group was not reported by Sims during his investigation of the Marsh in 1949.

(ii) Zooplankton

The Copepods, Cladocerans and Rotifers are the three major groups of minute animal life in freshwater. They represent one of the chief trophic links between the phytoplankton and the fish that dominate the higher trophic levels of aquatic ecosystems.

Comparisons between a survey conducted in Cootes Paradise during 1949 by Mr. E. M. Kay and a similar one completed in 1979 are shown in Table 1. An increase in numerical abundances of certain groups is the most apparent change. Populations of the Cladoceran Bosmina longirostris and Rotifers, particularly of the genus Brachionus, have more than doubled. Rotifers of the genus Conochiloides which were not reported 30 years ago, are now the most abundant representative. This has been accompanied by a sizable decrease in Copepods and the Cladocerans of the Genus Daphnia sp. This pattern in zooplankton community structure is typical of that which has occurred in other systems subjected to continuing eutrophication (Meshkova and Nikogosyan, 1977; Patalas, 1972).

The absence of Copepods of the genus Diaptomus from Cootes Paradise is consistent with its absence in Hamilton Harbour. Because of the free exchange of

water between these two basins, it had previously been part of the zooplankton community of both bodies of water. It disappeared from the Harbour in the early 50s and living specimens have not been encountered since. (Harris pers. comm.) This is significant because this genus is commonly found in oligotrophic waters. Its decline in Lake Ontario, Hamilton Harbour and Cootes Paradise is further indication of the deterioration in water quality within these three basins.

Population increases of Rotifers of the magnitude seen in Cootes Paradise are significant since their chief food consists of bacteria and organic matter rather than the phytoplankton. This represents a decrease in the efficiency of primary production utilization (Glivitz, 1975) as well as a change in the energy transfer pathway between trophic levels. Most water pollution involves changes in the pathways by which aquatic populations obtain energy and material. These changes lead to differences in the success of these populations and in the composition of aquatic communities.

TABLE 1. Quantitative Comparison of Zooplankton between 1949 and 1979.
(Data are combined from three similar stations in Cootes Paradise).

	1949 (Kay) (animals/liter)	1979 (RBG) (animals/liter)
Cladocera		
<u>Bosmina</u>	142.8	338.0
<u>Daphnia</u>	23.3	1.0
Copepoda		
<u>Cyclops</u>	54.0	3.6
<u>Nauplii</u>	97.0	176.0
<u>Diacyclops</u>	-	42.3
<u>Diaptomus</u>	0.3	-
<u>Canthocamptus</u>	0.1	-
Rotifera		
<u>Keratella</u>	79.0	128.3
<u>Asplanchna</u>	17.3	17.0
<u>Polyarthra</u>	106.8	27.3
<u>Filinia</u>	-	1.6
<u>Brachionus</u>	37.0	194.0
<u>Conochiloides</u>	-	330.3
<u>Notholca</u>	3.8	-
<u>Noteus</u>	5.8	-
Total genera	12.0	11.0

(iii) Benthic Fauna

Those aquatic invertebrates that live in, crawl on or attach to the bottom substrate of a body of water, are generally classed as benthic fauna. Associations of benthic macroinvertebrate are considered by many workers to be most accurate reflection of the prevailing environmental conditions, particularly the aquatic insects.

In a study of the insect life of the Marsh during 1948, Dr. W. S. Judd revealed a very diverse community with representation from no less than six orders of insects. Sixty-nine species of 23 families were identified (see appendix 3). During 1976, M.O.E. conducted a bottom fauna survey as part of its assessment of water quality in Cootes Paradise. Their findings are compared to the 1948 survey in Table 2.

A sharp decrease in total taxa and increased representation by Dipterans is evident, the largest proportion of which are of the family Chironomidae. The midges, as they are called when they emerge as adults, are termed "bloodworms" as larvae. This name reflects the red colour given some species by the presence of a red blood pigment which enables them to tolerate low dissolved oxygen concentrations (Pennak, 1953)

Another significant component of the present Cootes Paradise bottom invertebrate community although not shown in table are the aquatic oligochaetes of the genus Limnodrilus. They belong to a group of organisms largely associated with gross organic pollution and known as "sludgeworms". They were undoubtedly present during the 1940s but their status at that time is unknown.

TABLE 2. Comparison of relative abundance insect taxa represented between 1948 and 1976

	<u>Judd 1948</u>	<u>M.O.E. 1976</u>
Ephemeroptera	9.900	0.003
Odonata	1.500	-
Trichoptera	0.500	-
Lepidoptera	0.900	-
Diptera	87.100	99.980
Hymenoptera	0.100	-
Hemiptera	-	0.009
Total taxa		
orders	6	3
families	23	6
genera	57	9
species	69	-

(iv) Submergent and Floating-leafed Macrophytes

The aquatic macrophytes, in addition to converting chemical nutrients into food for other types of aquatic life such as waterfowl and muskrats, provide shelter and spawning habit for fish. For this reason, the importance of this component to the Marsh ecosystem cannot be overemphasized. Eutrophication, sedimentation, and the destructive habits of carp as mentioned elsewhere in this report, have all lead to alterations in both the abundance and composition of subsequent Marsh flora. A comparison between the time period 1946-48 and 1968-72 is made in Table 3 from the records of Judd, Tamsalu, Kay and Lord.

This table indicates a complete loss of several species particularly submergents such as Myriophyllum verticillatum and five species of Potamogeton and a reduction in status of others. Potamogeton Pectinatus is now the dominant

submergent in Cootes Paradise. It is listed by Stukey (1975) as very tolerant of turbid water. Potamogeton crispus has remained relatively unchanged in abundance. Both species were found by King and Hunt (1967) as resistant to carp action.

TABLE 3. From Lord (unpublished) Checklist of Submergent Aquatic Plants in Cootes Paradise Marsh.

	(Judd et al) 1946-48	(Lord) 1968-72
<u>Potamogeton berchtoldii</u>	1	-
<u>P. crispus</u>	2	2
<u>P. foliosus</u> var. <u>macellus</u>	1	-
<u>P. natans</u>	1	-
<u>P. nodosus</u>	2	1
<u>P. pectinatus</u>	2	3
<u>P. perfoliatus</u>	1	-
<u>P. zosteriformis</u>	2	-
<u>Najas flexilis</u>	1	-
<u>Elodea canadensis</u>	2	1
<u>Spirodela polyrhiza</u>	1	1
<u>Lemna minor</u>	3	3
<u>L. trisulca</u>	1	-
<u>Wolffia columbiana</u>	1	1
<u>W. punctata</u>	1	-
<u>Polygonum amphibium</u> var. <u>stipulaceum</u>	2	-
<u>Ceratophyllum demersum</u>	3	2
<u>Nuphar advena</u>	3	-
<u>N. variegatum</u>	3	2
<u>Nymphaea odorata</u>	3	-
<u>N. rubrosa</u>	3	3
<u>Myriophyllum verticillatum</u> var. <u>punctatum</u>	3	-
<u>Utricularia vulgaris</u>	3	1
<u>Megalodonta beckii</u>	1	-

- key
- 3 - plants in large numbers and dominant at few or many sites
 - 2 - plants which are not dominant but which are occasionally or frequently encountered
 - 1 - not common or dominant, collected once or twice
 - - plants not encountered

(v) Fish

The effect of eutrophication on the fish community of Cootes Paradise is difficult to interpret. Because of their mobility fish are subject to many influences which may affect their number and kinds. Alterations in biotic and/or abiotic components in Lake Ontario and Burlington Bay would also be expected to affect the fish community of the Marsh. For example the sea lamprey was determined by Christie (1974) to be a significant factor in the loss of many species of piscivorous fish in Lake Ontario. In addition, Whillans (1977) cited unstable water levels, increased turbidity due to silting and overfishing to be significant factors in the transition of Burlington Bay fisheries. However, eutrophication is regarded as responsible for at least some of the changes that have occurred (Larkin and Northcote 1969).

Mr. R. E. Turner operated gill and seine net sampling programmes from May 23 to August 19, 1947, as his part in the Warren Marsh project. Additional records from Ministry of Natural Resources commercial catch data for 1950-51 were obtained for comparison to recent surveys of 1973 and 1978 conducted by the Ministry and Royal Botanical Gardens, respectively in Table 4. The decline and complete loss of a number of species, many desirable game fish, and the increased representation of the undesirable rough fish is most apparent. The Bowfin (Amia calva), Golden Shiner (Notemigonus crysoleucas), Black Crappie (Pomoxis nigromaculatus), Small Mouth Bass (Micropterus dolomieu) and Lake Whitefish (Coregonus clupeaformis) have not been caught during recent surveys and the Largemouth Bass (Micropterus salmonoides) and Brown Bullhead (Ictalurus nebulosus) have declined considerably in abundance. However, increases have been noted in Carp (Cyprinus carpio), Goldfish (Carassius auratus), Gizzard Shad (Dorosoma cepedianum), and Suckers of the genus (Catostomus), all of which are considered tolerant of deteriorated water quality.

One species, the White Perch (Morone americana), which was not represented in 1947-51 surveys, now accounts for almost a quarter of the total fish biomass. The large population of this species illustrates its extensive invasion of the Lower Great Lakes since it gained access from New York State during the early 1950s. The fecundity and spawning habits of this species allows it to dominate quickly in a favourable habitat despite the presence of other established species (Scott and Crossman, 1973).

One interesting and ecologically important species is the Carp (Carpio cyprinus). Turner (1947) and Kay (1949) both suggested that carp were numerous enough in Cootes Paradise as to have a detrimental effect on the survival of rooted aquatic plants. Kay (1949) added that they were instrumental in the agitation of bottom sediments, thereby affecting water quality, yet none were caught by either gill or seine nets during fish sampling activities. This suggests that they are probably inadequately represented in both past and present survey results, and illustrates the problem of sampling bias when dealing with a mobile fauna. This fact is further supported by the results of a carp control programme conducted by Royal Botanical Gardens from 1952 to 1956 which yielded a total of 93,000 carp!

4. SUMMARY

Changes have occurred in both the composition and relative abundance of aquatic biota in Cootes Paradise Marsh. These changes are characterized as primarily a reduction in community diversity and numerical dominance by species considered tolerant of organic pollution. This applies, without exception, to the major biological communities considered, as Table 5 illustrates.

TABLE 4 - Comparisons of fish relative abundances between 1947-51 and 1973-78

	1947-51 (Turner + MNR)		1973-78 (MNR + RBG)	
	number	% abundance	number	% abundance
Alewife	19,783	40.600	1,570	35.600
Brown Bullhead	19,123	39.200	485	11.000
Pumpkinseed	3,030	6.200	69	1.600
Black Crappie	2,787	5.700	0	0.000
Gizzard Shad	2,001	4.100	343	7.800
Northern Pike	428	0.900	11	0.300
Large Mouth Bass	332	0.700	1	0.020
Rock Bass	289	0.600	6	0.100
Yellow Perch	179	0.400	17	0.400
Mooneye + L. Whitefish	168	0.300	0	0.000
Carp	166	0.300	517	11.700
Golden Shiner	164	0.300	0	0.000
Bluegill	134	0.300	10	0.200
Bowfin	120	0.200	0	0.000
White & Redhorse Sucker	114	0.200	126	2.700
White Bass	33	0.070	25	0.600
Goldfish	19	0.040	80	1.800
Small Mouth Bass	10	0.020	0	0.000
Channel Catfish	2	0.004	14	0.300
Log Perch	1	0.002	1	0.200
Long Nose Gar	1	0.002	3	0.050
Lamprey Eel	1	0.002	0	0.000
White Perch	0	0.000	1,069	24.300
Trout-Perch	0	0.000	47	1.100
Fresh Water Drum	0	0.000	2	0.040
Coho Salmon	0	0.000	2	0.040
Carp x Goldfish	0	0.000	8	0.020

TABLE 5 - COMPARATIVE TAXONOMIC SUMMARY

<u>COMMUNITY</u>	<u>TAXA</u>		<u>MOST COMMON GENERA</u>	
<u>Phytoplankton</u>	<u>Classes</u>	<u>Genera</u>		
1946	6	55	Closterium, Stephanodiscus, Scenedesmus, Selenastrum, Micractinum, Aphanizomenon	
1978	5	44	Scenedesmus, Chlamydomonas, Euglena, Cyclotella, Chlorogonium	
<u>Zooplankton</u>	<u>Classes</u>	<u>Genera</u>		
1949	3	12	Bosmina, Polyarthra, Brachionus, Daphnia, Cyclops	
1979	3	11	Bosmina, Brachionus, Polyarthra, Conochiloides	
<u>Benthic Macro-invertebrates</u>	<u>Families</u>	<u>Genera</u>		
1947	23	57	Chironomus, Ablabesysia, Caenis	
1976-77	6	9	Chironomus, Glyptotendipes, Limnodrilus	
<u>Submergent and Flating Macrophytes</u>	<u>Families</u>	<u>Genera</u>	<u>Species</u>	
1946-48	10	13	24	Ceratophyllum, Myriophyllum, Utricularia, Elodea
1968-72	5	8	10	Potamogeton, Lemna, Nymphaea
<u>Fish</u>	<u>Families</u>	<u>Genera</u>	<u>Species</u>	
1947-51	12	16	22	Alosa, Ictalurus, Dorosoma, Lepomis, Pomoxis
1973-78	12	15	20	Alosa, Morone, Dorosoma, Cyprinus, Ictalurus

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APPENDIX I - Objectives and Water Quality Goals for Cootes Paradise.

Objectives (April 1975)

1. First and foremost, to maintain this water and marsh habitat with contiguous lands as a wildlife sanctuary by protecting the integrity of habitats for a rich variety of flora and fauna through a firm stand on all activities which interfere with diverse ecological interactions and militate against such a preservation policy.
2. To provide limited public access and interpretative facilities for public education and quiet appreciation only to an extent consistent with No.1 above.
3. To continue to provide reasonably natural aquatic and terrestrial habitats for studies in environmental science by students at all levels.

Use Goals (June 1975)

1. For Resident Organisms
The aquatic habitat of Cootes Paradise must be made suitable for the needs of a full range of resident organisms common to similar habitats in southern Ontario, including birds, animals, amphibians, invertebrates, and plants.
2. For Migratory Birds and Spawning Fish
Cootes Paradise, with other major natural aquatic areas, plays an important role in successful bird (particularly waterfowl) migration, in both spring and autumn. Water quality influences and production of food and cover for migrating waterfowl.

Both native and introduced lake fish enter Cootes Paradise and its tributaries to spawn. Water quality must be conducive to their survival and for the survival of fry which hatch and journey back to Lake Ontario. Water quality must be such that Cootes Paradise can play its part in regeneration of fish serving the resurgence of fishing in Lake Ontario.
3. For Aquatic Studies
Present high coliform counts in the inflows of Chedoke Creek and upper Desjardins Canal prevent any use of these areas for aquatic studies beyond those of researchers trained to work in polluted waters. Water quality must be such that school classes and the public on interpretive excursions will not contract skin diseases or infections in handling specimens or by dipping into the water.
4. For Recreation
While it is not suggested that the waters of Cootes Paradise meet the standards of total immersion sports, coliform counts must be drastically lowered for quiet boating to be encouraged without health hazard.

APPENDIX 2 - List of Phytoplankton of Cootes Paradise Marsh,
April 28 - September 21, 1978

Cyanophyta

Myxophyceae

ChoococcusMerismopedia

Hormogonales

Oscillatoria

Chrysophyta

Bacillariophyceae

Centrales

MelosiraStephanodiscusCyclotellaSurirellaMeridion

Pennales

SynedraNaviculaGyrosigma

Xanthophyceae

Heterococcales

Ophiocytium

Chlorophyta

Chlorophyceae

Volvocales

Chlamydomonas SphagnicolaChlamydomonasPandorinaCarteciaChlorogonium

Chlorococcales

GolenkiniaPediastrumCoelastrumDictyosphaeriumPlanktosphaeriaOocystisLagerheimiaAnkistrodesmusClosteriopsisTetraedronScenedesmus QuadricaudaScenedesmus bijugaScenedesmus acuminatusScenedesmus arcuatusCrucigeniaTestrastrum staurogeniformeTestrastrum heterocanthumQuadrigulaActinastrumTetrademusKirshneriellaMicractiniumChlorellaPolyedriospsis

Tetrasporales

Elakstothrix

Zygnematales

ClosteriumCosmariumStaurostrum

Euglenophyta

Euglenophyceae

EuglenalesEuglenaPhacus

Pyrrophyta

Cryptophyceae

Cryptomonas erosaCryptomonas ovataRhodomonas

APPENDIX 3 - List of Insects of the Dundas Marsh in 1948 (from Judd)

EPHEMEROPTERA

Baetidae

- Caenis simulans
Callibaetis fluctuans

ODONATA

Lestidae

- Lestes rectangularis

Coenagriidae

- Enallagma ebrium
Ischnura verticalis

Aeschnidae

- Anax junius

Libellulidae

- Libellula quadrimaculata
Sympetrum vicinum
Leucorrhinia intacta

TRICHOPTERA

Psychomyiidae

- Polycentropus flarus

Hydrotilidae

- Agraylea multipunctata
Oxyethira verna
Orthotrichia americana

Leptoceridae

- Leptocercus americanus

LEPIDOPTERA

Pyrilidae

- Nymphula gyralis
Nymphula oblitalis
Nymphula icciusalis
Nymphula badiusalis
Acentropus niverus

DIPTERA

Tipulidae

- Arctotipula illustris
Limonia moniliiformis
Helius flavipes

Culicidae

- Anopheles quadrimaculatus
Anopheles occidentalis
Culex apicalis
Culex pipiens
Mansonia perturbans

Mycetophilidae

- Phronia rustica

Tendipedidae

- Pelopia punctipennis
Ablabesmyia monilis
Procladius bellus
Procladius culiciformis
Pseudochironomus middlekauffi
Polypedilum pedatum
Tanytarsus nigricans
Tendipes tentans
Tendipes sp.
Glyptotendipes atrimanus
Glyptotendipes lobiferus
Cricoptopus trifasciatus
Spaniotoma lucida
Spaniotoma sp.

Heleidae

- Sphaeromias longipennis
Probezzia glabra
Atrichopagon sp.

Stratiomyidae

- Odontomyia vertebrata

Dolichopidae

- Dolichopus deterius
Pelastoneurus vagans
Hydrophorus sp.
Sympycaus sp.

Lonchopteridae

- Lonchoptera dubia

Syrphidae

- Platycheirus quadratus
Lejops stipatus

Muscidae

- Lispe albritarsus
Lispe uliginosa
Hylemyia cana
Spaziphora cincta

Tetanoceridae

- Sepedon fuscipennis
Melina schoenherris

Ephydriidae

- Scatella picea
Setacera atrovirens
Notiphila olivacea
Notiphila sp.
Dichaeta caudata
Hydrellia griseola

HYMENOPTERA

Ichneumonidae

Zaleptopygus hartii

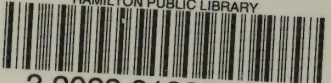
Cremastus hartii

Apsilops hirtifrons

Chalcidae

Chaleis canadensis

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